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IMPROVEMENT OF WATER-RESISTANT COTTON FABRICS

Agricultural Research Service
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[3] Mention of company or trade names is for information and convenience only and does not imply endorsement by the U. S. Department of Agriculture over firms or products not mentioned.

I. METHODS FOR IMPROVEMENT OF CLOSING OF FABRICS BY SWELLING

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INTRODUCTION

Research on the making of water-resistant cotton fabrics has been in progress at the Southern Regional Research Laboratory for a number of years. It has included the development of fabrics of extra high pickage but of lighter weight (9)[3] than fabrics made earlier, which are to be discussed below. This earlier work was centered around swelling-type, water-resistant fabrics. For the present purpose, these are fabrics which resist the passage of water largely by virtue of fiber swelling, which results in a closing, or self-sealing, effect within the fabric when it is wet. Such fabrics may have a water-repellent finish, but are distinguished from ordinary water-repellent fabrics by the more effective utilization of swelling, as a "second line of defense" against penetration by water. Both are distinguished from fabrics waterproofed with a continuous impervious coating by being permeable to air and to water vapor.

Portions of this work have been summarized (7, 31), but the many factors involved have not been presented in detail heretofore. Much material of general interest is included on cotton fabric construction and finishing, apart from effects on water resistance, with tables of unique data. Such material concerns comparative strengths, elongations, and other properties of yarns and fabrics made from extremely immature as well as mature cottons; also, physical properties of fabrics woven with normal to unusually high numbers of picks per inch (Parts III and IV). Data of this nature have not been available heretofore because such fabrics had not been made. Finally, some of the effects on fabric properties, especially on air and water resistance, at separate steps in finishing are included (parts III, IV, and V), as well as special tests which have resulted in new views on water resistance (Part V).

The early work was done in cooperation with the Quartermaster Corps when the oxford fabric was of great interest for army combat clothing. Interest in other construction has since increased because tightly woven oxfords have objectional features. For example, oxford fabrics of sufficiently dense construction for effective swelling lack drape, and tend to be stiff and boardy, especially when wet. However, the all-cotton oxford is of continuing interest, and principles to be discussed are applicable to some fabrics of other constructions. A much heavier fabric of oxford construction could be woven as unlined cotton firehose to replace unlined linen hose in case of an emergency shortage of linen.

SWELLING-TYPE FABRICS

That swelling can play an important part in the resistance of some fabrics to the passage of water is obvious from the rapid wetting and closing off of an unlined firehose under water pressure. Effects of swelling were evident also in suitably designed fabrics (22) made from rayon, with its well known high swelling capacity. The present research proceeded on the assumption that swelling could be an important factor also in the water resistance of cotton fabrics.

One of the oldest products of swelling-type fabric is the unlined linen firehose: other products include linen canvases for tents, covers, and water bags. Only comparatively recently have successful swelling-type fabrics been developed from cotton. These include unlined cotton firehoses (12, 14, 26, 27); and cotton fabrics of lighter weight developed by F. T. Peirce and his coworkers, known as Shirley, "L", or Ventile[4] fabrics (29). The research leading up to them seems never to have been reported in detail, although important points were covered by Peirce (25).

The British Ventile fabric development was based on Egyptian cotton, whose staple length gives it an advantage for such goods. Since Egyptian cotton would probably not have been available in this country, for extensive use under emergency conditions, nor, in fact, long-staple American cotton, the broad problem was to make effective fabrics from American cottons which would be readily available in quantity.

[3] Arabic numbers in parentheses refer to Literature Cited at the end of this publication.
[4] Mention of company or trade names is for information and convenience only and does not imply endorsement by the U. S. Department of Agriculture over firms or products not mentioned.

In this first paper are explained several possibilities for improvement of the water resistance of swelling-type fabrics. This introductory discussion is based somewhat on "theory," but to a far greater extent upon the actual experience of working with many cottons, yarns, and fabrics. Since the fabrics in each group to be described illustrate effects of two or more of the main factors or variables, some of the general principles are covered first.

FABRIC CONSTRUCTION

The oxford weave was adopted as the main construction for the experimental work for several reasons: 1. Some of the best self-sealing (unlined) linen firehoses are regularly made in this weave. 2. It was adopted by Peirce for his swelling-type fabrics of lighter weight, as well as his cotton firehose. 3. The oxford allows the use of a large number of warp ends (high sley), was of interest to the Quartermaster Corps, and was later described as the "tightest of the conventional weave" (16). 4. It met some of the important requirements to be discussed below.

In oxford weave two threads are laid together and woven as one, so that they correspond roughly with a wider, flatter single warp end. Requirements met by this weave are illustrated by a linen firehose which represents an almost ideal case (Figure 1). The warp has a large amount of crimp and the filling almost none, so that the filling lies in a "plane" of maximum density flatwise through the center of the cloth. Hence, one might say that the greatest width of the filling yarn lies in the plane, and since all warp ends pass up or down through it the greatest possible number of times it constitutes a plane of maximum density. In such a structure the yarns can be expected to swell against each other with a minimum tendency toward deflection from the plane. Thus the oxford weave should contribute toward the best possible tightness and the most effective swelling in this central plane.

A similar arrangement of yarns was found in a much lighter weight oxford fabric. A section (Figure 2) which was cut flatwise showed the filling yarns as of nearly uniform and approximately equal widths, lying equally spaced between the warp ends. This means that the filling had very little crimp and lay mainly in a central plane of maximum density.

In seven samples of Ventile oxfords of tight construction, the filling was found to be somewhat distorted from the central plane, although the "best" of the group, identified as LM-5 (Figure 3), shows the cut ends of the filling nearly in a straight line, indicating that they were nearly in a central plane.

Another Ventile fabric (L-32), cut across the filling while dry, shows the yarns not well in line, but a section cut while the fabric was wet and swollen shows the fabric shrunken and considerably changed in shape and the filling yarns well alined as though in a central plane (Figure 4). However, this may not represent the actual state in an uncut swollen fabric, because sections made in the other direction, across the warp (Figure 5), were not consistent with the filling sections, either wet or dry, and failed to show the filling lying in a straight line and, therefore, centrally within a plane.

The general conclusion is that there must be a zone of maximum density through a fabric to enable it to close by swelling, but that this zone may have appreciable thickness and not always follow a theoretical plane through the center of the fabric.

As a possible disadvantage, it is generally recognized that high-sley oxford fabrics are low in tear strength, which would be particularly objectionable in military fabrics. Peirce[5] stated, however, that in his experience they had given very little trouble from tearing.

A few plain weaves comparable to some of the oxford fabrics of high pickage were made, and found similar in closing capacity. It is understood that the Quartermaster Corps has expressed the opinion that a tight plain weave could be employed for slightly better water resistance when tear strength was not a limiting factor. The greater portion of the research to be reported is equally applicable to both plain and oxford goods.

[5] Private communication, F. T. Peirce.

Finally, if two warp ends woven as one are considered preferable to the single ends of a plain weave, more warp ends might seem still better. However, when a filling thread crosses even two warp ends it begins to take on the character of a float; if it crossed 3 or 4 ends it might really act like a float. The presence of floats is objectionable because if a cloth intended to be self-sealing has floats, segments of the yarns swell along the cloth where they are ineffective, and the yarns pass through the critical plane fewer times, resulting in a looser structure, less easily closed. The reasons for the selection of the oxford weave have seemed adequate for the use of this construction for the comparative studies of different cottons, yarn treatments, and effects of finishing on swelling-type fabrics. No record is known of different styles of construction being thoroughly studied from the swelling point of view. Preference for other constructions, such as sateens, for water-resistant fabrics is based on overall performance where, apparently, closing by swelling is not an important factor in meeting the requirements.

IMPROVEMENT THROUGH SELECTION OF COTTON

Some cottons appeared to have properties, aside from staple length, which made them more suitable than others for swelling-type fabrics. This was apparent from the fact that yarns of similar structure made from different cottons allowed different amounts of seepage of water in an orifice test (35). In this test, samples of yarn of equal lengths and weights in orifices, really holes through metal blocks, are put under pressure of water containing a wetting agent, to swell the cotton, and amounts of seepage through it are measured. Orifices are not fully closed in the usual tests for two reasons: First, it is too difficult and impractical to insert enough dry cotton yarn in an orifice to fully block it after the cotton is swollen. Second, differences between cottons, or tendencies arising from changes in other variables, can be observed when there is seepage instead of complete closing.

The contribution by swelling of different yarns, or different cottons in yarn form, to closing capacities of fabrics have been judged very satisfactorily by means of orifice test seepages because yarn drawn tightly into an orifice has much in common with yarn in a dense oxford fabric. Tables which follow show that the general behavior of comparable grey fabrics made from different cottons, in resisting passage of water, corresponded very well with the results of orifice tests on their constituent yarns.

When yarns made from various cottons were tested there was less seepage through those made from cottons containing the larger proportions of immature fibers, which indicated that such fibers have a greater closing capacity; the obvious implication was that immature fibers swell more than mature fibers.

There now appear to be differences in the swelling in water of different cottons, depending upon the presence of more or less immature fiber. No entirely acceptable quantitative expression had been obtained for greater swelling of immature cotton, in spite of extensive study (23, 36, 37). Subsequent adaptation of the use of the centrifuge has indicated swelling capacities of about 52% and 73% for mature and immature raw cotton (Part V). While these figures may seem high, they are consistent with the amount of swelling determined necessary to stop the flow of water in an orifice test. The usual test sample of air dry cotton yarn occupies 66% of the orifice volume. Some cottons swell enough to nearly close off the remaining 34% of air space. If air dry cotton is assumed to contain 7% of regain, an equivalent amount of dry cotton would have to swell by nearly 69% to just fill that space. The "dry cotton" base for this value is the volume of cotton equivalent to its density in water, 1.61(17, p.95). To this volume, amounts of regain (by weight) are additive as amounts of swelling (by volume) (See Part V, Special Methods).

Effect of Size of Fiber. Differences in seepage or degree of closing in orifice tests may result from differences in the capillary systems within yarns as determined by the differences in size alone of mature and immature fibers. As indirect evidence, seepage through the nonswelling fiber vinyon was much slower through

samples with fine filaments than through a sample of equal weight with coarse filaments (Table I). Similar results were obtained with highly swellable fibers, three rayons which were essentially alike except in filament denier.

In another procedure to demonstrate the effect of fiber size without the complication of swelling, a nonswelling liquid was used in the orifice test The immature cotton retarded its flow more than the mature cotton but not to so great a relative degree as when water was used (35). Hence it is apparent that the finer (immature) cotton fibers act, according to their size, in the same way as the finer filaments of other fibers to contribute significantly to extra closing capacity. They should similarly retard leakage of water through fabric not fully closed by swelling, but would hardly come into effect at complete closing. As shown later, the fine, immature fibers may contribute greatly also to low air permeability, a related phenomenon. The possible difference in sizes and in corresponding numbers of fibers is illustrated by two cottons used in comparable fabrics (Part III). The cottons were reported as of 5.6 and 3.6 micrograms per inch weight-fineness, for the mature and the immature respectively. Hence the immature had 55.5% more fibers in the cross section of an orifice test sample of a given weight than the mature cotton, and a correspondingly finer distribution of the air space. Actually, of course, when such samples are wet it becomes a question of the relative sizes of the fibers after swelling and of the correspondingly smaller spaces between them, which are unknown quantities.

Effective Amounts of Immature Cotton. Any appreciable contribution of greater closing capacity by immature fibers will necessarily depend upon their amount, but this is not suitably represented by the maturity value. The maturities of the two cottons (above) were reported (20) as 92% and 44%, corresponding to 8% and 56% of immature fibers, respectively. These values are percentages by numbers of fibers, but the cottons must actually behave in most respects according to proportions by weight. In order to estimate these proportions, assumptions were made that the mature fibers in the two cottons were alike, that the immature fibers were alike, and that the significant difference was in their proportions. Then the weights per unit length of mature and of immature fibers were calculated from the data given, as 5.93 and 1.78 micrograms per inch, respectively. From these values, the relative weights of immature fibers in orifice test samples (or in comparable fabrics of equal weight), of these mature and immature cottons, were calculated as 2.5% and 27.6%. Thus, while there were, by count, 7 times as many immature fibers in the more immature cotton as in the mature, there was 11 times as much immature cotton by weight, because of the 55.5% more total fibers in a given weight. If immature fibers swell appreciably more, they should contribute greater closing in accordance with the weight present.

Orifice seepages of these same two cottons were in the ratio of about 12 to 1, so it seems clear that the finer capillary system or the possible greater swelling associated with immature cottons, either or both, might exert a considerable influence on the closing of an orifice or of a swelling-type fabric.

Although the weight relationships are important, the more familiar terms, maturity and fineness, are used in the succeeding descriptions and discussions of the cottons used, and of yarns and fabrics made from them.

Noncellulosic Constituents. The presence of greater proportions of swellable noncellulosic constituents, particularly pectin, has been suggested as a cause for the greater closing capacities of immature cottons. It seems unlikely that pectin had any great specific effect, because the pectin (estimated from analyses (20) as 0.56% and 1.23% respectively, for cottons of 92% and 44% maturity) would apparently have had to swell to a much greater degree than the cotton itself for the extra 0.67% of pectin to be determinative.

Further, that the noncellulosic constituents do not exert an important effect through swelling has been shown by orifice tests on cotton yarns before and after purification treatments (Table II). Two major noncellulosic constituents, protein and pectin, are completely removable for all practical purposes, and several other noncellulosic materials partially removable by boiling in dilute sodium hydroxide. Hence samples of the yarns were boiled in 2% solutions of sodium hydroxide, in an open ves-

sel for 2 hours and other samples for 6 hours in a kier at 15 lb. pressure. The orifice seepage values for each yarn were changed relatively little by either boil and, more important, the ratios of seepages from cotton to cotton remained practically the same whether boiled or unboiled. That is, pectin was not determinative because its removal did not cause the seepage of the immature cotton to approach the higher values of the mature. The treated cottons swelled to so nearly the same degree as the cottons with the original noncellulosic constituents that virtually no extra closing effect can be attributed to these constituents. There was, however, an indication by higher seepage of a small loss in swelling capacity by each of the open-boiled cottons which may correspond with the similar reduction of swelling from open scouring in finishing (Part IV and V).

Packing of Fibers. It has been suggested that better packing of immature fibers may contribute to their better closing capacity. However, with a sample of given weight in an orifice of fixed size, better packing of a high proportion of immature fibers would apparently not contribute to better closing, because it would result in either open space or less well-packed fibers in some part of the orifice and cause a tendency toward relatively greater seepage.

As more direct evidence, fabrics made from immature fibers were found not to be consistently thinner, as they should have been if the fibers could consistently pack together in the yarn and cloth appreciably better than mature fibers. Rather, out of 9 pairs of fabrics made from 4 pairs of yarns representing mature and immature cottons, 7 of the fabrics made from immature cotton were thicker, rather than thinner (Part III and IV).

Tests Used in Selection of Cotton. Since the results of the orifice test depend on the same factors that are considered in selection of yarns for swelling-type fabrics, this was the test preferred whenever it could be employed. The more familiar and convenient methods applicable to cotton fiber can, however, be used. These methods include microscopic examination of fiber cross sections; differential dyeing (15) which readily indicates the presence of any great number of immature fibers; conventional methods for the determination of maturity; and methods of estimation of fineness by airflow, from which maturity is sometimes inferred. Cottons selected by such methods for immaturity or fineness can be expected to make effective water-resistant fabrics, if they do not have to be scoured. The most immature cottons were not succesful for finished fabrics (Part III) where scouring was required. Fine, mature cottons seem promising, but there was not opportunity to do sufficient work with them.

The centrifuge, which can be used for the estimation of swelling, offers a more direct test for the selection of cotton or of yarns for swelling-type fabrics. The technique employed was not published until after most of the present experimental work was completed, so it was not used with the raw cottons. Relative values were obtained for a group of yarns (Part IV), and swelling was estimated in connection with the study of finishing (Part V).

IMPROVEMENT IN THE YARN

Properties of linen and cotton yarns required for use in unlined firehose were discussed in an earlier article (14). These properties of linen yarns include high strength, high bulk density, (low air space), low twist, and low elongation, in addition to good swelling capacity. The requirements are much the same for yarn for other swelling-type fabrics.

Peirce and Gardiner (26, 27) recommended yarn (undoubtedly combed) of low twist, the latter allowable because, with long staple cotton, a low twist would still give adequate yarn strength. Peirce also emphasized the need for smooth uniform yarn (25), which implies combing is advisable, and no doubt necessary for fabrics of light weight, most of the present work was done with carded yarn. Yarns made from the most immature cottons were very rough and uneven but were effective especially in the fabrics before finishing. Results might even be better in some instances with carded yarns; for example, they showed 16% less seepage in orifice tests of 8 pairs of comparable combed and carded yarns made from

Acala 1517 cotton. Singles and plied yarns, and twist multipliers from 1.7 to 6.2 were included; 256 observations were made on each group, carded and combed, with few inconsistencies. The use of carded yarns is indicated for coarse and heavy goods, although a pronounced difference in seepage alone would not determine whether any particular fabric should be made from carded or combed yarns.

Low twist (25) in a yarn would seem to offer the advantage of imposing less restraint on swelling than high twist, and orifice tests (35) showed a pronounced trend to less effective closing with high twists. However, for oxford fabrics within the range of twists which could be used with American cotton there was relatively little difference. At one extreme, strands of fibers not twisted had exceptionally good closing capacity in the orifice test and thus indicated that soft yarns might be expected to pack together better than hard yarns in the weaving of a fabric to yield a more uniform structure. In the other direction, high twist should offer the advantage of making yarns of higher bulk density with less internal air space to be filled by swelling, although they may tend to be rounder and harder upon wetting, instead of swelling readily into adjacent space.

Twists of yarns for swelling-type fabrics to be made from ordinary cotton will necessarily be determined by the practical considerations of manufacturing of yarn for satisfactory cost, spinning, and weaving rather than by small possible advantages in swelling capacity. Singles, or plied yarns of relatively high twist, can be used as filling[5].

Ordinary differences in twist are not very significant for tight fabrics such as were woven, because swelling of the cotton in them is affected more by the density of the resulting fabric than by that of the yarn before weaving (Part V).

Warp yarns were all plied with moderate twist opposite in direction to that of the singles; and all fabrics were woven without warp sizing, which has several advantages: 1. The effects of using different cottons can be compared, unchanged from their natural state except by mechanical processing. 2. Fabrics of different construction can be compared, uninfluenced by added size, by wet treatment necessary to remove size, or by any possible residual size. 3. There is no uncertainty concerning the increased interfiber and interyarn space which might result from the removal of size and would need to be closed by swelling.

Since the filling yarn does not need to be plied[5], the use of singles equivalent to a plied yarn would mean lower cost and some relief in case of a shortage of twisting capacity. Two-ply filling was used in most of the present work, but where comparisons were made with filling of equivalent singles, there was little difference in overall performance (Part II). While three-ply yarn is supposed to have advantages in roundness or fullness of cross section in evenness, the yarns available were best used as two-ply. Also, all but 2 of 10 yarns used in the 7 light-weght Ventile fabrics mentioned earlier were two-ply.

Low elongation is necessary in yarns for firehose so that the hose wall will not stretch unduly and leak under water pressure. Of various methods tried for processing yarn while wet under tension to reduce its elongation before weaving into firehose, the only one considered promising for oxford fabrics was yarn mercerization. This process was employed by Peirce and Gardiner (26, 27) for firehose, but is understood as not necessarily used for the yarns going into all of the Ventile fabrics. Observation under the microscope of fibers from 6 such fabrics indicated that at least 3 of them were mercerized, probably as yarn. Mercerization under tension adds somewhat to the closing effect of cotton (Part II), presumably largely through an increase in swelling capacity; reduces yarn stretch; makes the yarn more compact; and enables it to pack into cloth with less free air space to make swelling more effective.

Need for adjustment in fabric construction would be expected in order to obtain the best possible result from improvement of the yarn by any process which would make it more compact. A tendency to greater openness of texture, such as one actually observed (Part II, Table I), could be offset by the use of heavier yarns or closer weaving; but further redesigning might be required to avoid undue gain of weight in matching a given fabric made from similar ordinary yarns.

USE OF A SUPPLEMENTARY SWELLABLE MATERIAL

If the starch of warp size could be left in the goods, unchanged, without fear of loss or decompositon later, it would help close a fabric by swelling, as was indicated by orifice tests on sized yarn. It is quite obvious that a permanent size, swellable upon wetting, which would not interfere with dyeing or other necessary processing, might be very desirable for some swelling-type fabrics, especially for uses other than as clothing.

The problem of producing a swelling-type unlined cotton firehose from ordinary American cotton was solved (14) by introducing into the yarn a supplementary swellable material which would not dissolve in water. When the yarn was woven, it carried into the fabric this additional material as a permanent part of the structure, where it not only filled a small percentage of space, but, when wet, aided in closing the fabric by swelling into some of the most critical remaining space. It can be easily seen, from Figure 1, that if a swellable agent was **added to the yarn** it would contribute toward closing the fabric in the critical plane, better than if applied to the cloth surface. It would be present where the swelling is most needed and it would not readily come out from wear.

The only promising swellable material found was Ceglin, a commercial hydroxy ethyl cellulose which makes up with caustic soda and water to a paste which can be padded onto yarn. After neutralizing, washing, and drying, the treated yarn is usually more compact from the incidental squeezing and the adhesive effect of the cellulose derivative; and is more suitable for weaving into a tight fabric with a minimum of air space. The same material, as applied to firehose, was used on yarn woven into fabrics of lighter weight, with the predicted result of improving their water resistance. It is virtually a permanent size although it was put on both warp and filling (Part II).

It would be much simpler to treat the fabric than the yarn, but the swellable material applied to the goods after weaving could not be effective unless enough was used to fill or coat the fabric. However, the Army had a water bag which apparently met requirements, made from cotton duck impregnated and coated **in the piece** in a manner which was no doubt simpler than using treated yarn (1).

In addition to the other requirements, the added material should not scour out if the goods are to be finished, and it should dye like the cotton. The hydroxy ethyl cellulose had a greater attraction than cotton for direct and vat dyes, and tended to cause a mottled appearance when treated cloth was dyed in the piece.

An added material, if too soft at the relative humidity of the weave room, may cause difficulty from shedding or rubbing off during weaving. A fabric with an added swellable agent might, though swelling easily and closing effectively, wet through readily so that it would be objectionable for clothing. The addition of any appreciable amount of swellable material to yarns intended for fabrics of closely specified weight per square yard might necessitate redesigning of the fabric to allow for the extra weight. It is evident that supplementary swellable material is of rather limited use unless needed for some special purpose.

IMPROVEMENT IN CLOSENESS OF WEAVE

A possible change in fabrics to improve their closing by swelling was tighter weaving. Although the numbers of warp ends were considered to be near the maxima that could be used, the possibility of increasing the number of filling picks was suggested by the Kreuzwalke, (cross rod cradle), which had been reported from Germany. A replica of this device was constructed in the Cotton Mechanical Laboratory. and the first fabrics of increased pickage were woven with it on the loom. Improved loom attachments were then developed (21) and were used in weaving later fabrics which had up to 36% more picks per inch than fabrics made heretofore for the same purposes. Pronounced improvements can be made, with only moderate increases in weight per square yard.

Cover factor is important in the design of closely woven fabrics and affords a means for comparisons of fabrics which are similar. In

investigations of water-resistant fabrics (16, p. 117) it was noted that the sum of the warp and filling cover factors will serve as an index of the overall cover factor or "closeness" of the weave. It was concluded from the tests which correspond best with rainfall that thickness and tightness are the two most important factors in fabric construction with respect to penetration and absorption of water. Thickness is necessarily limited by the weight allowable. The combined cover factor should be at least 45 for oxford fabrics.

Seven Ventile fabrics of about 4 to 8 oz. / sq. yd. had cover factors of 45.4 to 51.5. Many of the fabrics of the present investigation have had factors above 46, as shown in tables that will follow. A very high cover factor in an unsuitable weave may not ensure effective closure by swelling. There were considerable differences, also, in water resistance between some of the comparable fabrics made from different cottons even though cover factors (and constructions) were the same.

There seems to be very little opportunity for improvement of water resistant fabrics through finishing except by avoiding harmful practices. Effects of finishing are discussed later (Parts IV and V). Possible improvement of water resistance by new or better water repellency treatments was outside the scope of this investigation; it is assumed that in commercial production, advantage can be taken of any new development that adds to repellency.

CAPILLARY SYSTEMS IN WATER-RESISTANT FABRICS

The minute spaces between fibers in yarns, and spaces between yarns in fabrics are regarded as capillary systems. For example, the seepage in an orifice test shows that there is a continuous system of pore spaces. The combined effect of the pores or capillaries was shown in two ways to be like that of a capillary tube: 1. Seepage through samples of cotton yarn in a hole through a thin metal plate was in inverse proportion to that through a similar but longer hole in a thicker plate. 2 Seepage through fine-filament, nonswelling vinyon yarn was proportional to pressure.

Fabrics have similar but more complex capillary systems. Some of the pores or capillaries spiral along the yarns in the direction of the twist, like some of the pores in the oriffce test samples. It is generally true that cotton yarns are dense at the center and decrease in density outward. As yarns lie in fabrics they may press tightly together but some of the contacts of yarns are through less dense regions, and there may even be holes at intersections. With tighter weaving the pores tend to become smaller, and it can be assumed that the interyarn pores tend to approach the interfiber pores in size. If such equalizing could be attained, the fabric would constitute a homogeneous capillary system. This ideal is probably not attainable, and the resistance to penetration by water of high sley oxford fabrics, for example, may be due in greater degree to interfiber pores between yarns than to interfiber pores within yarns. Leakage of water through cloth takes place through the less dense region or even through holes, for there is probably never a completely uniform texture. Hence any improvement with density can hardly be a change from one overall uniform density to another, and comparisons in this study are made between fabrics which are not completely uniform.

The fabric pore systems are regarded as generally similar to capillary tubes with respect to passage of either air or water, although there has been no simple check on such similarity. There is an entirely unknown change in size of pores, also, when fabrics become swollen, which results in new capillary systems. However, the experimental fabrics of subsequent papers are regarded as representing for some purposes capillary systems.

"THEORY" OF WATER RESISTANCE

The effort throughout this work to make dense fabrics may seem inconsistent with some of the stated requirements for water resistance. However, it should be noted first that the term "water-resistance" is not always used in the same sense. Baxter and Cassie (8), for

example, were discussing repellency, wetting, and penetration, and thinking mainly of wool fabrics, when they said that dense fabrics are not suitable; that fibers should be far apart and not able to draw together; and that yarns of high density give conditions favorable to ease of wetting and breakdown under rain. Obviously they did not refer to conditions favorable to closing by swelling; such conditions may not be the most favorable for water repellency. Baxter and Cassie's wool fabrics were not of as high densities as swelling-type cotton fabrics. They go on to say that the constituent yarns should be soft so that their density is not very different from the overall density of the cloth, which should be as uniform as possible. On the other hand, cotton fabrics to close by swelling should be uniformly dense rather than uniformly soft, as already explained.

Segall (32) published a theory of water-resistant fabrics relating to yarn properties required for fabrics of a given density to have maximum water resistance. It has to do with penetration and presents a relationship between the pore sizes in the fabric and the interfiber distances on the surfaces of the yarn comprising the fabric pore walls. While this factor should possibly be taken into account under some circumstances, this theory is not having further attention here for several reasons. It was not published until after the present experimental work was practically complete. While concerned with the penetration of water through a fabric, it does not take into account effects of swelling of the fibers which changes the effective sizes of fibers and of pores in the fabric. Finally the emphasis in the present investigation has been on fabrics of different densities, rather than on fabrics of equal densities with changes in other variables.

SUMMARY

Considerations regarding possible improvements of water-resistant cotton fabrics to take advantage of the swelling of the cotton have been presented. These considerations include factors in the design, manufacture, and finishing of such fabrics, in their more general aspects. Reasons have been indicated for the selection of various conditions employed in the experimental work to be described. This more general material was taken up first because nearly every experimental fabric has involved two or more of the main factors or variables. The oxford style of weave was adopted as very suitable for these fabrics. The contribution of swelling to water resistance depends upon a plane or zone of maximum density flatwise through the center of the fabric, dense enough to close by swelling.

Early tests indicated possibilities through the use of the less mature cottons, whose advantage was subsequently decided to be attributable partly to greater swelling and partly to finer capillary systems. Noncellulosic constituents do not swell enough differently from the cellulose of cotton to determine any advantages of one cotton over another. Immature fibers can be expected to respond in fabrics according to their proportion by weight rather than to the number present. Immature fibers did not pack together more closely in fabrics than mature fibers.

In order to determine the possibilities for the use of American cottons of ordinary staple lengths, carded yarns of low to medium twists were used for most of the fabrics. Advantages and disadvantages of sizing and of other treating of yarn before weaving are pointed out. Treating yarn could include the use of a supplementary swellable material, as used earlier in unlined firehose.

Closeness of weave could be improved by the insertion of more picks per inch. The yarns as submitted to orifice tests, and the fabrics, are regarded as capillary systems of minute openings or pores, which differ from fabric to fabric with fineness of cotton and numbers of picks per inch, and which change during finishing. Permeabilities to air and to water are dependent upon these systems.

The indications were subsequently confirmed that swelling of the fibers may contribute appreciably to the water resistance of a suitably constructed fabric.

Table 1. *Effect of size of fiber on seepage (filament yarns)*

Fiber	Filament denier	Seepage		
		ml	*ml*	*ml*
Rayon	6.0	...	14.2	3.4
Rayon	2.5	...	4.9	1.4
Rayon	1.7	...	2.6	.8
Vinyon	14.3	31.0	...	...
Vinyon	3.5	11.3	...	...
Vinyon	1.2	6.6	...	...

Table II. *Effect of purification of cotton on swelling (seepages in orifice tests)*

Nature of cotton and of yarn	Grey yarn		Open-boiled		Kier-boiled	
	Observed	Ratio [1]	Observed	Ratio	Observed	Ratio
	ml		*ml*		*ml*	
Rowden 41B, 8/1	11.8	3.6	13.8	3.9	11.0	3.7
Acala 1517, 6/1	6.6	2.0	7.2	2.1	6.1	2.0
Wilds 13, 17/1	3.3	1.0	3.5	1.0	3.0	1.0
92% Maturity, 13.75/2	11.9	11.9	16.7	11.0	12.3	11.2
44% Maturity, 13.75/2	1.0	1.0	1.5	1.0	1.1	1.0

[1] Ratio of seepage to that of the lowest in each vertical group or pair taken as 1.

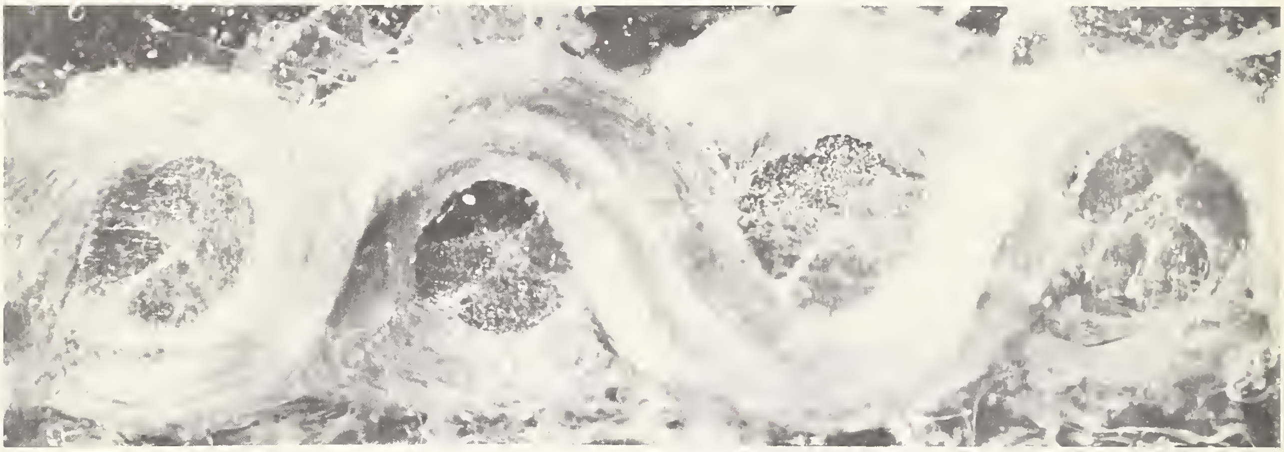


Figure 1A. *Section of linen firehose fabric cut across the filling to show nearly ideal construction.*

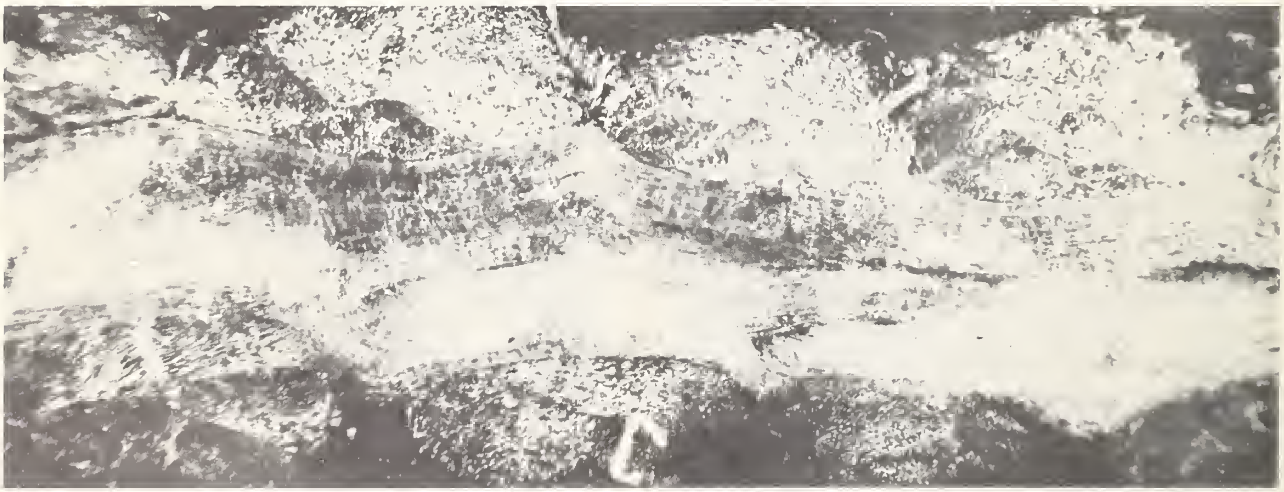


Figure 1B. *Section of linen firehose fabric cut along a filling yarn to show that it is not forced out of line, but is indented by the warp ends.*

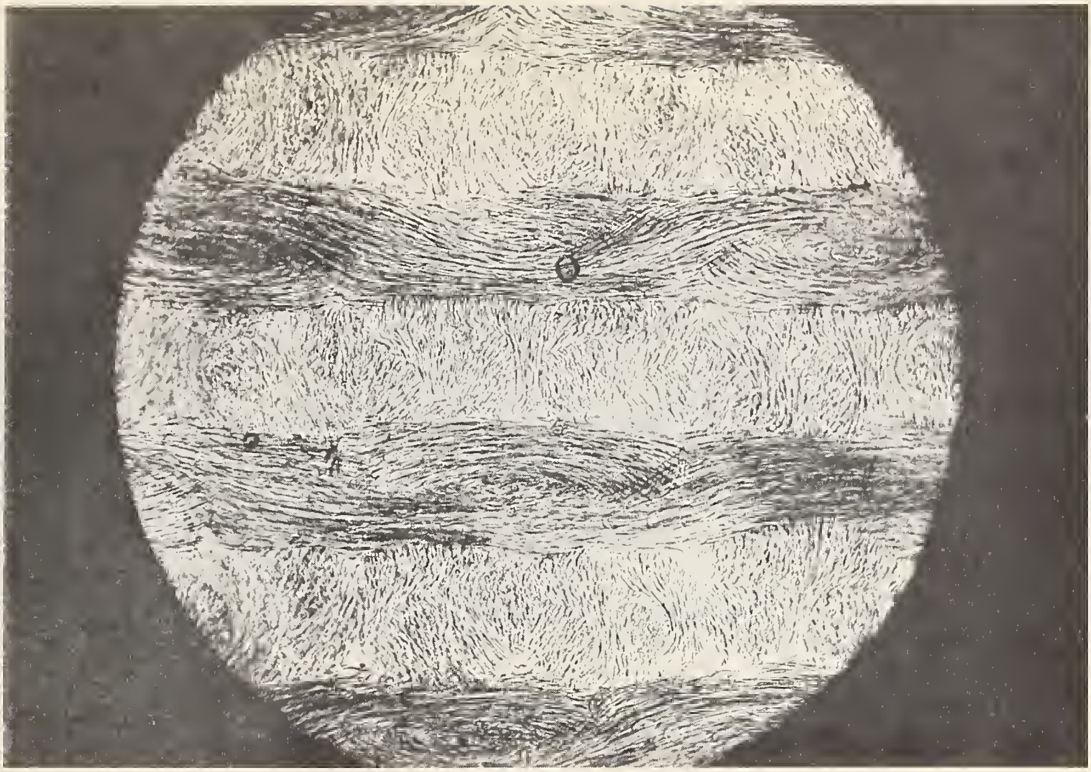


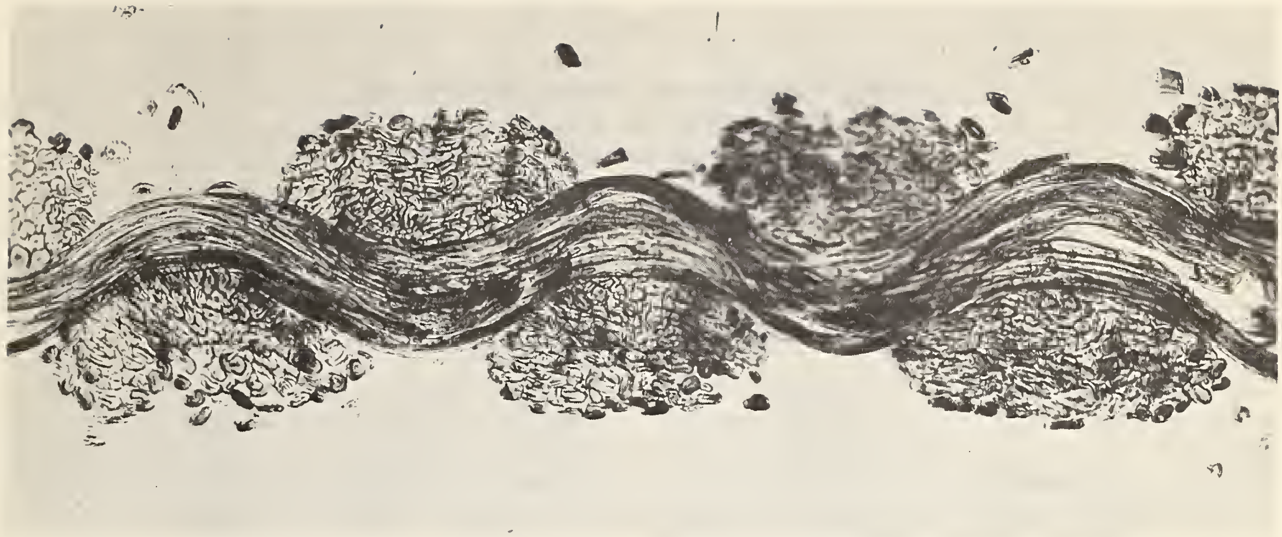
Figure 2. *Section flatwise through an oxford fabric, approximately at the plane of maximum density.*

Figure 3. *Section across filling of a Ventile fabric (LM-5) showing that filling picks lie nearly in a central plane.*

A

B

Figure 4. *Sections across the filling of a Ventile fabric (L-32, 4-5 oz. per sq. yd.) (A) Dry. (B) Wet and swollen.*



A

B

Figure 5. *Sections along a filling thread of a Ventile fabric (L-32) (A) Dry. (B) Wet and swollen.*

II. EVALUATION OF CLOSING EFFECTS OF SWELLING FABRICS MADE FROM TREATED YARNS

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INTRODUCTION

In work on water-resistant fabrics it has become apparent that the term "swelling type" needs a more specific definition. It seems reasonable that the fabric, if it is to be considered of swelling type, should allow the transmission of no water at all or of only some limited quantity under specified conditions when it is fully swollen. The setting up of a definition for swelling-type fabrics was beyond the scope of the present work, but the need will be particularly evident from the special tests which showed that swelling was not as effective in many fabrics as it may have appeared to be in more conventional tests (Table I).

Special attention is given first to adaptations of some of the usual tests of water resistance to bring out the contribution of swelling. Then follow descriptions of fabrics made from yarns which were mercerized or had an added supplementary swellable substance.

SPECIAL TESTS FOR SWELLING-TYPE FABRICS

In the absence of recognized methods specifically for the evaluation of the effect of swelling, measurements have been made of leakage through fabric samples, preswollen by wetting to eliminate effects of water repellency, to compare the attainable effects in different fabrics. Some of the usual tests for water resistance and repellency have also been used that overall quality can be judged in familiar terms.

Preswelling for Tests. There are two principal ways in which cotton fabrics can take up the water that causes swelling—wetting by liquid water, and absorption of water from its vapor. Both have been tried for preswelling samples of fabric for tests for permeability to water (leakage) after swelling.

Tests which include preswelling by water have been employed by others. A British publication (3) indicates that "percolation" tests have been made by soaking fabric samples in water for 24 hours and then observing leakage through them at a given head (100 cm.). Minor et al. (22) reported less seepage under hydrostatic pressure through a cotton oxford fabric which was presoaked under a 100 cm. head of water, than through samples of the same fabric not presoaked. In neither reference was there mention of prewetting to insure the mose effective possible swelling.

In the absence of prewetting, an air-dry tightly woven cotton fabric immersed in water will retain more or less air which may ultimately be displaced, or be dissolved in the water. Such air should become saturated at once with water vapor, which can then be taken up by the fiber to cause swelling. Swelling in this way could supposedly become complete. A complicating factor is that a fabric exposed to water vapor can not only swell but may retain entrapped air in such a way as also to increase the water resistance (Part V).

Hence, the long-time soaking of fabric not prewetted seemed to offer less assurance of effective swelling than a shorter time following a boil to eliminate air. Since objections can also be raised to the latter procedure, comparative experiments were performed.

For preswelling the sample, one procedure was to place an air-dry sample of water-repellent fabric under distilled water at 100 cm. head and hold it there for 24 hours. In the other procedure the test pieces were prewetted by boiling for 10 minutes and then allowed to soak for 50 minutes in distilled water under a few centimeters head at room temperature. It was shown that boiling for 1 hour had no advantage over 10 minutes (Part V). All test pieces were squeezed lightly between paper towels to remove and prevent reabsorption of excess water before weighing or testing.

The two procedures were found not to be equivalent in tests on samples of two fabrics (several years old), one made from mature cotton and one from immature. No. 117 and 122 described in Part III. Specimens of these finished fabrics placed in water under a head of 100 cm. at 80° F., soaked for 24 hours and then tested for amount of leakage in the Suter[3] apparatus (see below) allowed passage

[3] Mention of company or trade names is for information and convenience only and does not imply endorsement by the U. S. Department of Agriculture over firms or products not mentioned.

of 93 ml. and 96 ml. in the forst 5 minutes for the mature and immature cottons, respectively (Part V). Specimens boiled and then soaked for the shorter period of 1 hour allowed passage of the much larger quantities of 264 ml. and 509 ml. of water, respectively. The results show clearly that the methods were not equivalent in these tests. The same mature-cotton fabric (No. 117) was tested both ways in another series of tests (Part V) with similar results.

The smaller leakages through the samples soaked for 24 hours in both series of tests implied better swelling and better closing by this procedure, but since the fabrics that were boiled first and then soaked, and regarded as fully swollen, leaked more, something else seems to have affected the result. This is probably, as mentioned above, enclosed air held in the fabric is such a way as to increase its water resistance and give a false impression of better closing by swelling than actually was obtained. More evidence for this view will be presented in Part V.

Since, in contrast to the previous experiments, results from the two methods of preswelling came out equal in other special tests described later (Part V), it is evident that more work would be required to show conclusively that either method is more effective than the other. Since the boiling procedure seemed to give more assurance of maximum swelling, it had already been adopted as more convenient for the large number of samples which were tested; however, the presoaking without boiling may reflect more nearly some of the conditions met in service.

Wetting and swelling might be more rapid and more nearly complete if a wetting agent were used, but it would represent a still greater departure from service conditions than the boiling, which at least limits the test to water.

There are sometimes great differences between values obtained for leakage through replicate samples of a fabric, which may necessitate an excessive number of tests to obtain acceptable average values. It must be recognized that from sample to sample some indefinite part of the leakage may take place in a nonuniform manner through less dense areas at some of the yarn intersections. Any such "soft" spots must detract to some extent from the water resistance of the fabric. Even though some fabrics have responded as though they were not particularly uniform, there have usually been great differences in average level of leakage from one experimental fabric to another in the important comparisons. Results have apparently been in the right order, and trends could be recognized.

Apparatus Used. Two quite different types of apparatus, the Suter (5) hydrostatic and Bundesmann[3] (2) testers, were used to measure water resistance in terms of amounts of water passing through fabrics after preswelling.

In measurements on the Suter apparatus, examples of which have been discussed above, the column of water was merely set at a constant head of (usually) 86 cm. above the preswollen fabric, and the amounts of water were measured that passed through it in the time intervals indicated in the tables. The 86 cm. was the maximum which had been observed in the regular hydrostatic test in earlier experiments and was taken arbitrarily as likely to allow at least slight seepage through most preswollen fabrics to be tested, so that different degrees of closing could be readily recognized.

The other test for the amount of leakage of water through preswollen fabrics employed the Bundesmann apparatus, used as usual except for the wet test pieces and a longer time. This apparatus (Figure 1) provides a shower, normally at the rate of 3 inches of water in 10 minutes. Water was used at 80° ± 2° instead of the 50° to 70° F. specified. The time of exposure of prewet samples to the shower was usually 20 minutes and the test showed decreases in leakage with improvements in fabrics up to a level where there was no leakage during the 20 minutes. Beyond that point slight differences in closing capacity, observable with the Suter apparatus, could not be distinguished. This test has the disadvantage that the apparatus is not generally available. The Bundesmann test has undergone considerable study and the standard apparatus has been modified since these tests were made. The older form of British-made instrument was employed. Its use in the usual manner is mentioned in the next section.

CONVENTIONAL WATER-RESISTANCE TESTS EMPLOYED

Several of the usual water-resistance tests were used extensively. These tests are described in readily available sources (4, 5), and little more than the general nature of their indications according to findings of the Quartermaster Corps (16) will be mentioned here. Rain room, rain course, and actual field observations, when continued over long periods of time are, in this order, the most practical and desirable tests for water-resistant fabrics; but simpler equipment and methods must be employed for the many tests required during the development of fabrics and finishes. Of laboratory tests, those of three classes are of the most practical interest:

(A) Hydrostatic methods were represented in the work at the Southern Laboratory by the conventional test with the Suter type of apparatus (5), in which, under increasing height of water column, the head is observed when 3 drops of water have broken through the surface of the fabric test piece at different places. This hydrostatic pressure value bears some relationship to the suitability of the fabric for rainwear, and although the correlation is not well defined, the test is considered a valuable research and screening tool (16, p. 20). While considered to be not as suitable as other penetration tests for predicting rain performance, hydrostatic tests are of special interest for fabrics which are intended for water containers. The same apparatus was used to a limited extent for hydrostatic penetration tests through air-dry samples (5, 16) in which the water that flowed or leaked through was collected and measured.

(B) The second class of test was represented by the drop-penetration tester, the rain tester, and the Bundesmann apparatus. From the excellent correlation obtained between the drop-penetration test (5; 16, p. 22) and natural rainfall it had been concluded that this test is most suitable for predicting rain performance of a wide range of fabrics. For many fabrics to be described it was impractical to use the specified "minutes to collect 10 ml. of water," because the test would have lasted many hours. Instead, the amounts of water collected in 3 hours were reported (Part IV).

The rain tester (4, p. 148; 16 p. 24) sprays a fabric held vertically so that the water that penetrates is collected in a blotter and weighed. In the present study the amounts of water which penetrated some of the fabrics were so small that the samples were placed 6 inches from the horizontal spray nozzle instead of the usual 12 inches, and the test was continued for 20 minutes instead of 5. The maximum head, 8 feet, was used in all tests. The rain test in its usual form is considered (16, p. 32) most suitable for estimating rain performance of fabrics of the characteristic usually desired in civilian-type raincoats.

The Bundesmann tester was considered (16, p. 32) almost as satisfactory as the rain tester and had been found to offer no particular advantages when operated in the conventional manner. Since an apparatus was available, it was used at the Southern Regional Laboratory, but mainly in the special way described with prewetted samples. However, the conventional test allowed a comparison with reports on British Ventile fabrics. It is understood that one of the specifications for the latter is that there shall be no leakage in the usual Bundesmann test for 30 minutes, during a simulated 9 inches of rain. Of 25 of the new fabrics made and tested at the laboratory none showed leakage after 30 minutes; and only 2 of them when the test was extended to 2 hours. In contrast, a commercial 9-oz. water-resistant oxford fabric leaked 48.5 ml. in the 2-hour test; in fact, water usually penetrates through "ordinary" water-repellent goods within 10 minutes.

The fabrics mentioned that did not leak were by no means so tightly woven as fabrics eventually made, so that data in Table II will show why this test was but little used. In the loom-state the mercerized fabrics were better than the unmercerized and the Ceglin[3]-treated fabric was still better. There was, however, no measurable penetration of any of them after finishing during 2-hour periods, so that differences which might be of practical interest were not detectable.

(C) Absorption tests have not been reported, because there is no definite correlation between absorbency and closing by swelling, in the great variety of fabrics under consideration.

Except for tests on preswollen fabrics, all water-resistance or water-repellency tests are regarded as having been made on air-dry, or simply "dry," fabrics. Even though all samples were conditioned at 65% R. H. and 70° F., they could not be tested with water in the conditioning room; they were tested in a laboratory which was usually at about 76° and 50 to 60% R. H. Such differences in relative humidities to which samples may be exposed before testing have been reported to have no appreciable effect on results of the usual test for hydrostatic head(19).

OTHER PHYSICAL TEST METHODS EMPLOYED

Air permeabilities have been recorded to help show the properties of the new fabrics. Measurements were made with the Gurley Permeometer[3] (5) of cubic feet of air passing through 1 sq. ft. of fabric in 1 minute under a pressure drop of 0.5 inch of water. The closest woven fabrics allowed very little air to pass through, and some none at all. Since, however, readings could be obtained for all fabrics with the Densometer[3] (5), all were tested also with this instrument. The observations obtained, are in the reverse order numerically from those obtained with the Permeometer, because the time for a given amount of air to flow is recorded instead of the volume of flow in a given time. The time required for 300 cc. of air to flow through 0.1 sq. in. of fabric, with a 5-oz. cylinder, is shown. Agreements of duplicate tests were good, and good correlation between results by the two methods was observed (Part V).

The other physical tests usually made were thread counts, weight per square yard, thickness, percent crimp in the warp, breaking strength and elongation-at-break by the strip method on 1-inch widths, in both warp and filling directions, and trapezoid tear tests in both directions in the piece. There were no significant variations in these tests from the methods of the ASTM (5).

EXPERIMENTAL FABRICS

The fabrics, based on the 9-oz. oxford construction were made in pairs or in larger groups to allow comparisons of results from changing one or more of the most important variables, and all were woven without warp size as already explained. All fabrics were tested in the grey or loomstate, and most of them after approximately conventional finishing, which consisted of open-width (jig) scouring and dyeing, and treatment with Zelan AP[3] for water repellency. The cloth was not desized, mercerized, or sanforized and was tentered only once, in the grey. It was run with as little tension as possible and was usually finished from about 39 inches down to 36. Any shrinkage or stretch was indicated by change in thread counts. The laboratory finishing is described in more detail later (Part IV); and the results of tests on the finished goods are of most practical interest.

FABRICS MADE FROM TREATED YARNS

The main purpose in making the first experimental fabrics was to determine whether there would be advantages which might justify the extra trouble and expense of making swelling-type fabrics from processed yarns—either from mercerized yarns or from yarn containing an added supplementary swellable material.

A large number of fabrics made by the Institute of Textile Technology and reported by the Quartermaster Corps (16, p. 120) were made from mercerized yarn, and various conclusions were drawn from them. The yarns used were mostly 3-ply, and the cloth cover factors were 45 or higher. These fabrics undoubtedly had the advantage of greater swelling than if made from unmercerized cotton and were, therefore, no doubt more water-resistant than they would have been if made in the same

constructions from unmercerized cotton. There was no duplication between the work reported and that to be described below.

The 9 fabrics of Table III demonstrate the effects of numerous variables. They represent 3 different cottons and 16 different yarns, and allow comparisons of loom-state with finished goods throughout. Also, there were specific comparisons of fabrics made from mercerized and from unmercerized yarns including singles against plied filling yarns, of cottons with a moderate difference of maturity, and, finally, the effect of an added swellable material.

MATERIALS USED

Fiber and Yarn Properties. Fabrics of the first group were made from Acala 1517, a relatively long and fine cotton of rather low maturity (Table IV). This cotton was actually selected from the size and shape of cross sections of its fibers. The cotton was combed and spun into singles, and twisted in the opposite direction into 2-ply yarn (Table IV). Also, portions were spun into singles equivalent in size to the 2-ply yarns, for use in comparable fabrics.

Portions of the yarn were spun slightly coarser for mercerizing to allow for decrease in size during the process, but remained a little heavier than the grey yarn. The warp yarns were mercerized by a conventional warp process; and the filling yarns by a commercial skein process without stretching or shrinking. The filling as observed under the microscope was not as well mercerized as the warp.

The last 4 fabrics were made from 2 Santan Acala cottons which, differing by 11% in maturity, were rated as of average fineness and fine. The less mature was the finer, in accordance with its larger number of immature fibers. Each of the cottons was carded, in contrast to combed (above), spun, and twisted into 2-ply yarns similar to those described for the first group of fabrics except that lower T. M.'s were used in plying the filling. Portions of the yarns were mercerized in the laboratory on a frame-type apparatus (13) to simulate the usual warp product. They came out the same in size as the unmercerized (within 1 to 1-½) except one which was 3 to 4% finer. The mercerized yarns tended, as usual, toward, moderate gains of strength, and losses in elongation-at-break (Table IV).

In order to provide yarns with an added swellable agent, portions of the grey Acala 1517 yarns were treated with Ceglin[3], alkali-soluble hydroxy ethyl cellulose. The amount applied was rather large and is roughly indicated by changes in yarn numbers (Table IV), for example, from 24.1/2 to 20.8/2. Ceglin was used on the filling as well as on the warp. On the latter it served as a size and was, therefore, an exception to the general use of unsized warps.

Change in the weight of yarn by an added agent raises the question whether an allowance for the extra weight should be made in the cloth construction. The answer depends upon whether the intention is merely to add to the effect of the cotton, the purpose in the present case, or to substitute another swellable substance for part of the cotton, which would introduce various complications. Therefore, an adjustment in construction was not attempted.

Seepages observed in the orifice test on yarns are shown in Table IV. Treated Acala 1517 yarns gave improved results. The warp yarn was greatly improved by the mercerizing, but the filling yarn was improved less, apparently because of less satisfactory mercerizing. Ceglin contributed to the best closing of all even though it was weighed-in with the yarn sample and, in effect, substituted for cotton. The less mature (finer) of the two Santan Acala cottons in both warp and filling yarns, showed the better closing. Both cottons were improved by mercerizing.

Fabric Construction and Physical Properties. Five fabrics were made from the combed yarns of Acala 1517 cotton. Two of them were woven from untreated (grey) yarns, one having 2-ply filling and the other equivalent singles. Two were woven similarly from mercerized yarns; and one, of similiar weave, was of Ceglin-treated warp and filling (2-ply).

Since there were changes in weight during the processing of the yarns and no way of com-

pensating for them with certainty without extra experiments, the fabrics did not come out as closely comparable as might be desired. Differences in weights per square yard were consistent with the differences in yarn numbers. The weights were very near to the intended 9 oz. for the plain grey fabrics. The fabrics made from mercerized yarns were 4 to 5% heavier and correspond approximately with the 4 to 8% greater weights of the yarns. The fabric with the cellulose finish was about 15% heavier than the grey cloth, somewhat more than the corresponding 11% increase in weight of the yarn, and 10% thicker.

The fabrics were closely comparable in thread counts with a maximum difference of only 1-½ warp ends within the group and ½ filling pick. The maximum difference between the sums of the numbers of warp and filling threads of any 2 fabrics was 2, or just over 1%, so that the fabrics were alike in constructon for all practical purposes.

The corresponding mercerized and unmercerized fabrics made from Santan Acala cotton (Table III-A) were equal in weight, but both of those fabrics made from the less mature of these cottons were about 3% lighter. Warp and filling totals were within about ½% of each other.

Fabric strengths are affected by too many variables for general conclusions from so few examples, but in these specific cases the mercerized were somewhat stronger than the corresponding unmercerized fabrics; those made from the less mature cotton were a little the weaker but, as noted, were lighter in weight.

Air permeabilities were somewhat greater for the fabrics made from mercerized yarns than for fabrics from unmercerized yarns, in 4 comparisons by the Permeometer test (Table I-A), and in 3 of the 4 comparisons by the Densometer. The inconsistency of the fourth fabric may be associated with the 5% greater weight of the mercerized material (No. 34). Air permeability was considered reduced by the presence of Ceglin. It may be of special interest that fabrics made from the less mature (fine) cotton also had lower air permeability.

DISCUSSION OF RESULTS

Loom-State Fabrics. The loom-state fabrics (Table I) had considerable water resistance, presumably attributable to a repellency effect due to natural waxes, and to partial closure by swelling. We have in this group some of the best of evidence that swelling of cotton can contribute to closing of fabrics. All four fabrics made from mercerized yarns were better than those made from the similar grey yarns. This was not apparent from the hydrostatic heads required to cause penetration by water of the air-dry grey fabrics in the regular Suter test in comparison with the heads for the fabrics made from mercerized yarns, which were considerably lower. On similar tests, however, made on preswollen fabrics, the heads required to cause the usual three drops penetration were all much lower but the order was reversed, the fabrics from mercerized yarn requiring more than 60% higher heads than the unmercerized (data not shown). Further, in both the Suter and the Bundesmann tests on preswollen fabrics for amount of leakage, only 15 to 20% as much water passed through those made from the mercerized (Acala), yarns as though those made from the unmercerized (Table I-A, No. 31 vs. 33, and 32 vs. 34).

The mercerized Santan Acala fabrics (Nos. 125 and 128) were penetrated as somewhat lower heads than the unmercerized (Nos. 124 and 127) in the conventional hydrostatic test but in the rain test there was only 1/3 to 1/2 as much penetration through the mercerized as through the unmercerized fabrics, even though the latter presumably had more of the repellent natural wax present. Since the fabrics made from mercerized yarns tended to be more open when dry than those from unmercerized yarns, as shown by greater air permeability, it follows that their fibers must have swollen more effectively from the prewetting to effect the better closing displayed. Therefore, the explanation of the advantage of mercerization of the yarn, in these loom-state fabrics, lies principally in a real effect from greater swelling of mercerized cotton (below).

The cloth made from yarn with the added cellulose derivatives was much harder and stiffer than the others when wet, and might be regarded as not strictly comparable with them because of the added weight, but it con-

tained no more cotton. Although it has greater swelling capacity than the cotton, the Ceglin might not be as effective if it replaced cotton in a fabric. It swells to a softer gel than cotton and could not be expected to withstand mechanical action or high water pressure as well, unless held very firmly in a dense fabric structure. Because of their weight, tendency to wet through, and their stiffness when wet, fabrics of this type do not seem suitable for clothing. On the other hand, these features would probably not be objectionable for water bags and tanks. In the regular Suter hydrostatic test, the fabric from Ceglin-treated yarn was penetrated by water at the lowest head in the group but, in contrast, it showed by far the lowest measured leakage under a head of water when presoaked.

Fabrics made with singles filling (Table I-A, Nos. 32 and 34) had about the same air permeabilities and leakages of water as the corresponding fabric (Nos. 31 and 33) with equivalent 2-ply filling. Since there would be practical and economic advantages in using singles filling, it should be more fully evaluated.

Comparison of the two Santan Acala cottons, which differed in maturity, indicates that a real difference in water resistance may result from a relatively small difference in fineness and in closing capacity due to a somewhat larger number of immature fibers, in general agreement with results in Part IV. This was true of fabrics in the loom-state, whether or not the yarns had been mercerized.

Finished Fabrics. Portions of the fabric were finished and whenever comparisons within a group are described, they were finished together.

All four fabrics made from mercerized yarns had better water resistance after finishing than those made from grey yarns. The finished fabrics made with singles filling yarn had better water resistance, whether mercerized or not, but slightly greater air permeability than those made with 2-ply filling yarn.

After finishing, the fabrics made from the more immature Santan Acala cotton, mercerized and unmercerized, were not so clearly better than the fabrics made from the more mature, as they appeared to be in the loom-state. Fabrics of the more immature cotton were better in the rain test, and in the Bundesmann test with preswollen samples, but not as good on the Suter apparatus with preswollen samples.

When compared after finishing, the Santan Acala fabrics from mercerized yarns had higher tear strength in both directions than those made from unmercerized yarn. This agrees with observations (24) that mercerization in the piece improves tear strength. The gain is probably explained by such effects as strengthening of the yarn, making it smoother and more compact, and possibly, to slight texture opening, which permits yarn to shift more easily in the piece under stress. While the use of mercerized yarn would, in general, have the same advantages as mercerizing in the piece, it would have similar disadvantages, plus the disadvantage of greater cost.

The finished fabric made from Ceglin-treated yarn maintained the same relation to the finished fabrics made from grey and mercerized yarns as in the loom-state and the highest after finishing, probably owing to loss of Ceglin as indicated by the large decrease in weight per square yard during finishing.

Samples of several fabrics, Nos. 31, 33, and 35, were tested in the rain room at the Philadelphia Quartermaster Depot and results appear in a publication (16 p. 109).

The general quality of these fabrics was good although they were surpassed later. The finished fabrics of Santan Acala cotton, whether made from unmercerized or mercerized yarn, all resisted penetration in the Bundesmann test (on air-dry samples) for 2 hrs. with no leakage of water (Table II). This is considered very good performance, and it compares favorably with reports regarding Ventile fabrics. Cover factors, calculated for the loom-state, were 45.8 to 46.7, not extremely high, but above the minimum considered necessary for military rain-resistant materials (24).

Swelling of Mercerized Cotton. Mercerized cotton yarn can be regarded as more effective through greater swelling capacity than unmercerized and, at the same time, it offers a more favorable physical form. That its swelling capacity is greater follows, for example, from data of Welco et al. (37, Fig. 10). Data from the curves for mercerized and unmercer-

ized yarns in this figure, and calculations according to methods given in Part V, indicate the mercerized yarn had swollen by 71% and the unmercerized by 58%. The difference of 13% represents potential extra closing capacity, about 22% greater than that of the unmercerized cotton.

That swelling and differences in swelling capacity were important determining factors in the water resistance of fabrics described above is apparent from centrifuge tests (Table V) on the fabrics of the Santan Acala cottons. These fabrics were closely comparable, because yarns which were very nearly alike were made into fabrics of the same construction. Amounts of swelling estimated according to Part V, and relative percentages of greater swelling capacity due to immature fibers and to mercerization are shown. Even the 11% greater number of immature fibers in the less mature cotton apparently contributed 5 to 8% to greater swelling. Mercerization contributed 18 to 21%; immaturity and mercerization together gave 27% greater swelling than did the more mature unmercerized cotton. These results imply greater closing capacities even though swelling of the fabric as a whole may not necessarily be a measure of closing capacity. For example, owing to differences in fabric construction, there may be differences in water resistance which may not be reflected in estimations of swelling.

Work on the application of mercerization or of additive swellable materials was not carried further, because of impractical features of such treatments, although better fabrics could be developed in both of these directions. It is quite certain that effective swelling-type fabrics could be made more readily from mercerized than from unmercerized yarns. It can be inferred also from results reported in Part IV that merely scouring and dyeing in yarn form, along with weaving in a suitable construction could result in fabrics capable of closing more effectively by swelling.

SUMMARY

Mercerization of yarn according to ordinary procedures increased its swelling capacity and improved it in physical form for use in self-sealing water-resistant fabrics.

The addition of a swellable material greatly improved the capacity of a fabric to close by swelling, but appeared to be more suitable for firehose, water bags, and tanks than for clothing.

A difference from high to average maturity of cotton made a slightly better-closing fabric.

Finishing detracted from water-resistance. The loom-state fabrics were usually superior in tests measuring closing capacity, such as the Suter leakage and Bundesmann on preswollen samples; they also withstood higher hydrostatic heads. In important tests on air-dry samples, however, such as the Slowinski rain test and the regular Bundesmann test, both intended to stimulate service, the finished fabrics were superior.

None of these fabrics were strictly of swelling type, although some of them were good water-resistant fabrics.

There was but slight difference between the use of singles and plied filling yarns.

Mercerized yarn, similar to the yarns used in these experiments, was estimated to swell by about 71% and unmercerized yarn by 58%. The experimental fabrics of mercerized yarn swelled more than those of unmercerized in about the same proportion. Although such apparent swelling may not necessarily be in proportion to closing capacity and water resistance of the fabrics, it seems to contribute appreciably to their effectiveness.

Table I. *Air and water resistance of fabrics*

Fabric number	Nature of yarn used in fabrics	Air permeability: Permeometer	Air permeability: Densometer (time/300 cc.)	Hydro-static pressure	Hydrostatic leakage, prewet samples: 25-cm. head	Hydrostatic leakage, prewet samples: 86-cm. head	Bundesmann penetration, prewet samples	Rain test, 8-ft. head sample 6 in. from nozzle
		ft³/min/ft²	*min:sec*	*head, cm*	*ml/5 min*	*ml/5 min*	*ml/20 min*	*gm/20 min*
A. LOOM-STATE:								
31	Untreated yarn, plied filling	1.4	6.36	79	731	...	66.	...
32	Untreated yarn, singles filling	1.4	5:30	93	1070	...	69.	...
33	Mercerized yarn, plied filling	1.5	5:24	58	168	...	9.2	...
34	Mercerized yarn, singles filling	1.5	5:42	56	191	...	8.7	...
35	Ceglin treated, plied filling	.57	16:32	47	81	...	.6	...
124	Untreated yarn, 91% maturity	.66	10:48	70	...	741	3.3	over 10
125	Mercerized yarn, 91% maturity	.72	8:24	54	...	463	.3	3.16
127	Untreated yarn, 80% maturity	.33	16:16	79	...	397	2.7	2.03
128	Mercerized yarn, 80% maturity	.66	9:15	61	...	313	.6	1.64
B. FINISHED:								
31	Untreated yarn, plied filling	1.6	5:35	46	1048	...	44.	...
32	Untreated yarn, singles filling	1.7	4:26	43	596	...	42.	...
33	Mercerized yarn, plied filling	1.5	5:57	55	479	...	23.	...
34	Mercerized yarn, singles filling	1.6	5:27	47	326	...	5.0	...
35	Ceglin treated, plied filling	1.9	4:09	38	170	...	6.9	...
124	Untreated yarn, 91% maturity	.78	8:02	57	...	2839	17.	2.99
125	Mercerized yarn, 91% maturity	1.0	8:24	61	...	928	12.	1.13
127	Untreated yarn, 80% maturity	.76	11:04	61	...	3245	11.	1.43
128	Mercerized yarn, 80% maturity	1.0	7:14	58	...	2220	8.0	.68

Table II. *Penetration in Bundesmann test*

Bundesmann penetration, conditioned samples				
	ml/20 min.	*ml/2 hr.*		*ml/2 hr.*
No. 31	Loom-state 3.3	Finished 0.0	No. 124	Finished 0.0
32	Loom-state 1.4	Finished .0	125	Finished .0
33	Loom-state 3.9	Finished .0	127	Finished .0
34	Loom-state 3.1	Finished .0	128	Finished .0
35	Loom-state 2.1	Finished .0		

Table III. *Physical properties of fabrics*

Fabric number	Construction: Warp	Construction: Filling	Weight	Thickness	Crimp in warp	Breaking tests[1]: Warp Strength	Breaking tests[1]: Warp Elongation	Breaking tests[1]: Filling Strength	Breaking tests[1]: Filling Elongation	Total cover factors	
	ends	*picks*	*oz/sq yd*	*in*	*%*	*lb*	*%*	*lb*	*%*		
A. LOOM-STATE:											
31	124	52.5	8.9	0.0208	21.5	156	38.3	116	7.7	44.4	
32	124	52	9.0	.0208	22.3	155	40.0	114	8.3	44.2	
33	123.5	52	9.2	.0208	20.5	163	36.7	138	7.7	45.2	
34	122.5	52	9.4	.0206	20.2	166	37.3	135	10.7	45.0	
35	123	52	10.3	.0228	22.6	141	33.3	131	5.7	47.0	
124	124	54	9.3	.0176	19.2	174	26.7	123	12.3	46.4	
125	124	55	9.2	.0165	14.4	175	24.0	146	10.7	46.7	
127	125	53	9.0	.0166	15.2	169	26.3	118	13.7	46.3	
128	124	54	9.0	.0165	13.6	175	27.7	135	12.7	45.8	
B. FINISHED:										Trapezoid tear Warp	Trapezoid tear Filling
										lb	lb
31	130	47	8.0	...	...	125	20.0	104	14.7		
32	128	47	8.0	...	...	142	22.3	98	15.7		
33	128	48	8.9	...	...	150	24.0	127	13.3		
34	128	47	8.7	...	...	151	22.0	113	16.0		
35	129	47	8.8	...	...	136	19.0	118	12.3		
124	130	53	9.3	.0170	15.6	148	25.7	114	16.7	16.2	5.7
125	128	54	9.6	.0174	16.0	157	25.7	138	15.0	17.6	8.0
127	130	52	8.8	.0162	14.4	143	25.0	104	15.7	14.2	5.6
128	130	53	9.1	.0170	15.2	150	24.3	119	15.7	17.0	7.3

[1] Strip breaks based on thread counts in the loom-state fabrics.

Table IV. *Fiber and yarn properties*

A. FIBER

Fabric number	Variety of cotton	Maturity (caustic soda)	Classer's designation Grade	Staple	Fineness (by weight)
		%		in	ug/in
31-35	Acala 1517	72	—	—	3.1
124-125	Santan Acala	91	SM	1-1/16	4.2
127-128	Santan Acala	80	SM	1-1/32	3.6

B. YARN

Fabric number	Nature of yarn	Yarn number		Twist multiplier Singles	Ply	Breaking tests, single strand Strength	Elongation	Seepages in orifice test
						lb	%	ml/10 min
31	Combed, grey	Warp	35.9/2	3.4	4.3	1.3	6.9	6.8
	Combed, grey	Filling	24.1/2	3.6	4.3	1.9	7.3	5.8
32	Combed, grey	Filling	12.1/1	3.6	...	1.8	8.7	7.6
33	Combed, mercerized	Warp	34.5/2	[1]	[1]	1.5	5.4	1.7
	Combed, mercerized	Filling	22.5/2	[1]	[1]	2.2	8.3	4.3
34	Combed mercerized	Filling	11.2/1	[1]	[1]	2.0	8.1	4.2
35	Combed, Ceglin treated	Warp	31.7/2	3.4	4.3	1.5	5.2	.6
	Combed, Ceglin treated	Filling	20.8/2	3.6	4.3	2.3	4.3	1.1
124	Carded, grey	Warp	33.8/2	3.5	4.2	1.2	6.9	6.9
	Carded, grey	Filling	22.1/2	3.5	3.8	2.0	6.4	7.6
125	Carded, mercerized	Warp	34.0/2	3.5	4.2	1.5	5.5	5.4
	Carded, mercerized	Filling	21.8/2	3.5	3.8	2.3	5.6	6.1
127	Carded, grey	Warp	34.2/2	3.5	4.2	1.2	6.9	4.5
	Carded, grey	Filling	21.9/2	3.5	3.8	1.9	7.3	4.2
128	Carded, mercerized	Warp	35.3/2	3.5	4.2	1.3	6.9	3.4
	Carded, mercerized	Filling	22.1/2	3.5	3.8	2.1	7.0	4.6

[1] Yarns were spun somewhat coarser, but T.M.'s were similar to those for the comparable yarns immediately above.

Table V. *Effect of maturity and mercerization on swelling (centrifuge)*

Fabric number	Maturity of cotton	Yarn treatment	Swelling of fabric	Relative increases [1] due to: Immature fibers	Mercer-ization	Imm. fibers and merc.
	%		%	%	%	%
124	91	None	31.1	...	...	...
125	91	Merc.	37.7	...	21.1	...
127	80	None	33.5	7.7	...	...
128	80	Merc.	39.4	4.5	17.6	26.7

[1] The relative increases were calculated from the percentages of swelling of the fabrics. Increases due to immature fibers were based on the values for the unmercerized and mercerized mature-cotton fabrics; increases due to mercerization were based on the corresponding unmercerized fabrics; the increase due to both was that of the mercerized fabric of immature cotton over that of the unmercerized fabric made from mature cotton.

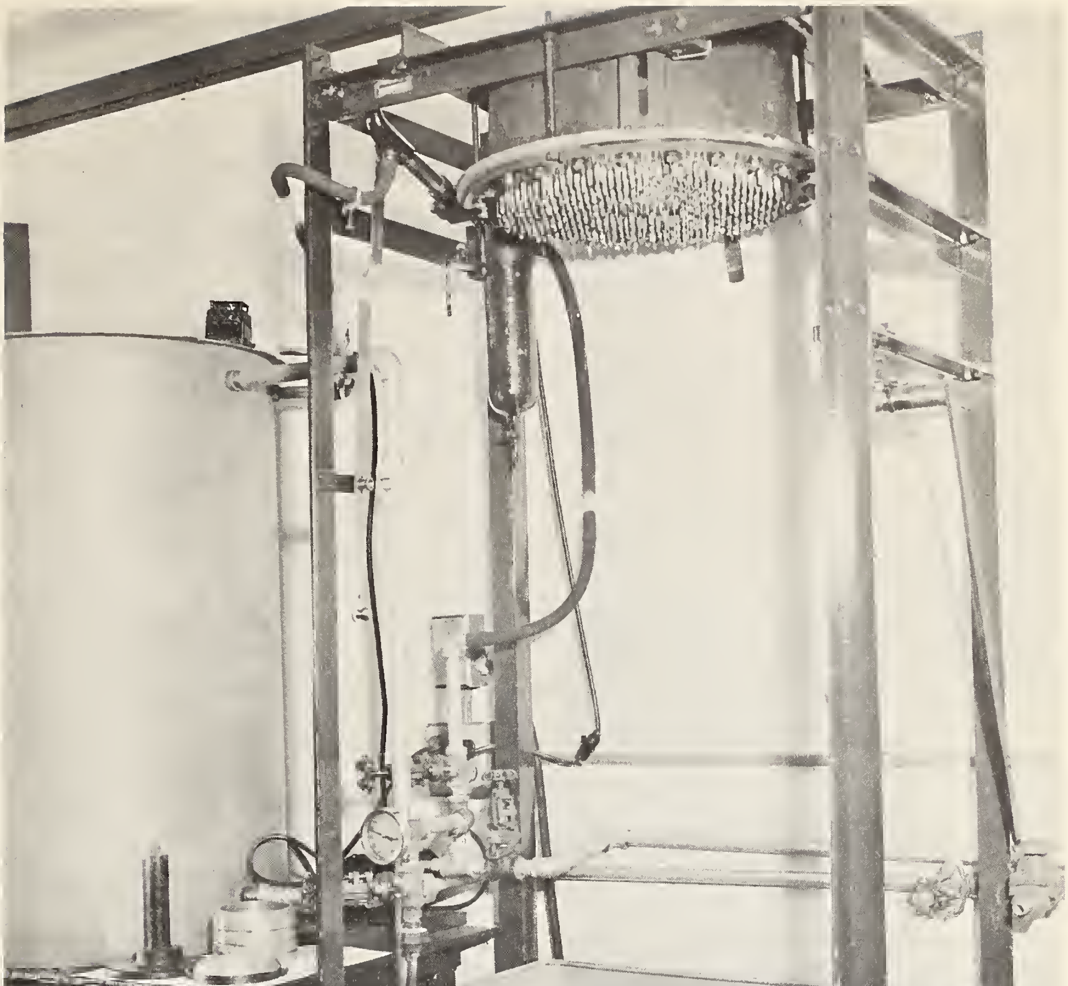

Figure 1. *Bundesmann water repellency tester. Water dropping from 304 fine jets simulates the action of a tropical downpour. Wipers, shown in one cup, rubbing on the undersides of the fabric samples, which rotate under the shower, imitate effects on a garment that is being worn. Absorption as well as leakages through samples is measured.*

III. EFFECTS OF MATURITY OF COTTON AND OF HIGH PICKAGE

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INTRODUCTION

Early observations had indicated that yarns made from immature cottons impeded the seepage of water through an orifice more than comparable yarns of mature cottons (35). Hence it appeared that the less mature cottons might be more favorable for making swelling-type fabrics, and a tendency in this direction was shown in Part II. This tendency was found to hold in exploratory tests, described below, of two cottons, very different in maturity, in comparable fabrics. Although the favorable effect was not so apparent after finishing, the influences of immaturity in cotton and of finishing were investigated further.

Also, since a means of tighter weaving by putting in more picks than normal became available (21), tests on this factor were included. Experimental fabrics in one group included several of plain weave. Another group, limited to the oxford weave, included a very immature cotton in comparison with a mature cotton, both with a wide range of picks per inch.

All fabrics were finished in a nearly conventional manner to show the effects of finishing on water resistance, particularly as dependent upon maturity of cotton and tightness of weave. As before, the principal finishing operations were scouring at full width on a dye jig, dyeing with vat colors, and treating with Zelan AP[3] for water repellency. None of the fabrics were desized, mercerized, tentered, or Sanforized.

This paper also includes unique physical test data on yarns made from cottons of very different maturities; and on fabrics made from such cottons with ordinary and with unusually large numbers of picks per inch. Methods of testing, with differences from normal methods, given in Part II. Some data in the tables are not discussed in the text.

EXPLORATORY FABRICS TO SHOW EFFECT OF MATURITY

The selection of the cottons for the first two exploratory fabrics was based on their greatly contrasting red and green colors when differentially dyed (15) and on the difference in cross sections under the microscope. Maturity tests conducted by the standard sodium hydroxide swelling method at the Southern Regional Research Laboratory (20) showed the coarser cotton to have a value of 92% and the finer cotton 44%[4].

Both cottons were of too short staple and too low quality to comb or to spin down to the usual yarn numbers for 9-oz. Army oxfords. Hence they were made into coarser carded yarns which were of rather low grade, and woven into 13-oz. oxford fabrics. Plied yarns were used in both warp and filling; and the fabrics were not exceptionally closely woven.

Although the cottons were very different in properties, the yarns made from them were closely comparable in size and twist, but very different in closing capacity in the orifice test (Table I). The grey fabrics were very closely comparable in weight and construction (Table II). Both fabrics shrank about 5% in width and increased about 10% in length during finishing, according to thread counts. This resulted in a net increase of about 5% in area, which made the fabrics somewhat more open and helps account for the decrease in weight per square yard.

The fabric made from immature cotton was less permeable to air and more water resistant, whether grey or finished, than the fabric made from mature cotton (Table III). After finishing, the preswollen fabric of mature cotton leaked less in the Suter[3] apparatus than before finishing, but the corresponding preswollen fabric of immature cotton leaked much more. Although the water resistance of the fabric of immature cotton was decreased, it still showed an advantage over the finished mature-cotton fabric. These two fabrics were tested in the rain room of the Philadelphia Quartermaster Depot and a slight advantage of the immature cotton was reported (16, p. 111).

[3] Mention of company or trade names is for information and convenience only and does not imply endorsement by the U. S. Department of Agriculture over firms or products not mentioned.

[4] Maturity values reported earlier by another laboratory were 83% and 40%, respectively. The disagreement between the two sets of results is considered unimportant for the present purpose because both indicate about equal large differences in maturity as determined on the two cottons at different times. The higher value, 92% and 44%, are being used here because of accompanying analytical data from the same samples. The lower values were utilized in previous reports (15, 16, 34).

EFFECTS OF MATURITY, WEAVE, AND PICKAGE

Next was a group of fabrics made from Acala 1517W cotton, available in 3 degrees of maturity, viz. 85%, 74%, and 58% (Table 1) rated as fine, fine, and very fine, respectively. These cottons in one known variety from the same source would normally be of equal perimeters and are considered to have differed in fineness in accordance with the principal variable of maturity. The most mature cotton of this group was finer than cottons of similar maturity used in other groups of fabrics, but there were no closely similar constructions for comparisons.

Yarns were spun with Z twist in the singles and made into 2-ply with S twist, suitable for the base 9-oz. fabric. Fabrics of both plain and oxford constructions were woven in the range of 52 to 71 picks. All fabrics of each cotton were made with the same unsized warp, and portions of all fabrics were finished.

Properties of the fibers, yarns, and fabrics, and results from the various tests are given in Tables I, IV, and V. Valid conclusions regarding the final fabrics cannot necessarily be inferred from their behavior before finishing.

The fabric of plain weave, No. 113, was slightly more water resistant, finished, than the similar oxford No. 110, in 2 out of 4 tests; it was not better in any of the tests in the grey. Since the plain fabric was about 1% lighter in weight and roughly 2% more open in texture, more tests would be required for a conclusive comparison between the 2 weaves.

The immature cotton was more effective than the mature in reducing air permeability, and in increasing water resistance in terms of leakage through preswollen fabrics, as well as in both hydrostatic head and rain tests on air-dry samples. These conclusions are the result of 18 comparisons of test values, from 3 pairs of grey fabrics, viz., 1 pair with 85% and 74% maturities in normal pickage, and 2 pairs with 85% and 58% in normal and in high pickage (Table V).

Increasing the number of picks by about 27% (to 68) improved the closing of the grey fabrics, but there was slight advantage in the use of a few additional picks beyond 68. Since the change in construction was only in the filling, the increase in weight at this point was only 13 to 14%.

The behavior of the fabrics was changed by finishing, and the immature cotton did not show as great an advantage. The fabrics of plain weave made from cottons with a small difference in maturity, 85% against 74%, were both more open after finishing, i. e., more permeable to both air and water in all but the rain test, where both showed improvement from finishing. However, the fabric of the more immature cotton was slightly the better in all cases.

Fabrics in the oxford weave made from cottons with a greater difference in maturity, 85% and 58%, in normal and high pickages, were all somewhat more open after finishing; and the immature became less effective than the mature-cotton fabric. Of the fabrics of the most immature cotton the one of highest pickage was reduced in air and water resistance relatively much more than that of normal pickage, in all tests except the rain test. The Bundesmann[3] test with preswollen fabrics is also an exception in that all high-pickage samples, grey or finished, showed no penetration and, therefore, excellent water resistance.

Extremes of Maturity and Pickage. Two more cottons with a very great difference in maturity were made into oxford fabrics, each in five degrees of tightness of weave obtained by increases in the numbers of picks with a given warp. The cottons, a Deltapine and a highly immature cotton of unknown variety, designated as "Sike," had maturities of 85% and 30%, and were of average fineness and very fine, respectively (Table I).

These cottons were carded, spun, and twisted in the opposite direction to the singles, to 30/2 (Table I), then woven into oxford fabrics. The number of picks in the finished fabrics went up 27% (to 70 and 71, respectively) above the number 56, the number for the initial fabrics in each series (Table VI).

The immature cotton had a much greater closing capacity in grey fabrics (Table VII). There were very consistent values with the changes in numbers of picks, and great and consistent differences between similar fabrics

of mature and immature cottons. The improvement in closeness of texture, or density of fabric, is brought out by the greater decrease in air permeability resulting from the use of immature cotton and additional decrease shown with each increase in number of picks (Figure 1). The chart shows that fabrics extremely impervious to air, for their moderate weight can be made from immature cotton. While objections to highly immature cotton are recognized, these results indicate again that it might find use in special products in which the large amounts of noncellulosic constituents are not too objectionable.

In the rain test for penetration the immature cotton showed a great advantage, and further improvement from increasing the number of picks. When the grey fabric samples were preswollen and the leakage through them was measured at 86 cm. head of water, there was a very regular decrease as the number of picks per inch was increased, with leakage at a much lower level through the immature-cotton fabrics. The extreme improvement is represented by the difference between 1,173 and 0.1 ml. leakage, brought about by the combined effect of the difference in the nature of the cotton and the increase in number of picks per inch (Table VII).

The properties of the fabrics and relationships between them were considerably changed by finishing. The rain test showed that the fabrics of this group as a whole were still good quality with respect to water resistance from the usual point of view. The fabrics made from the mature cotton showed a little improvement from finishing, but those from the immature cotton were not quite as water resistant as before. The fabrics of the immature cotton remained, however, slightly better than the fabrics of mature cotton after finishing. Other test results, however, including the lower hydrostatic pressure values after finishing, especially for the fabrics of immature cotton, indicated that the water resistance was not as good as before finishing.

The tests on preswollen samples, as well as on the air-dry samples, indicated that swelling of the fabrics may not have contributed as much to water resistance, even of the well-closed grey fabrics, as expected.

The grey fabrics showed very little or no leakage when tested preswollen on the Bundesmann[3] apparatus, and no important differences were brought out. Leakages in this test were increased by finishing, and fell into a consistent series of decreasing values with increasing picks through the group of fabrics made from each cotton. The results, especially for the finished fabrics with the greater number of picks would still be considered good. However, the three finished fabrics of highest pickage of immature cotton leaked more than those made from the mature cotton, while the two of lowest pickage leaked less. This is a reversal of behavior and confirms similar results with the Suter apparatus, discussed below. As a general comment on the good quality of the fabrics, none of the finished samples tested dry, of mature or immature cotton, high or low pickage, leaked any water during 2 hours under the Bundesmann shower. This is excellent performance.

DELETERIOUS EFFECTS OF FINISHING

As one of the most significant results, a tendency toward increases in the openness of the mature-cotton fabrics by finishing, and a more pronounced opening of the immature-cotton fabrics, were shown by increases in air permeability. Opening of fabric by scouring is demonstrated directly in Part IV in a special study of some of the important features of finishing.

As to closing by swelling, the fabrics were all less effective after finishing. When tested in the Suter apparatus after preswelling, leakage was greater through every fabric and, most notable of all, the behavior of the three fabrics of immature cotton with the largest numbers of picks was reversed, as also in the Bundesmann test. They leaked more after finishing than the corresponding fabrics made from mature cotton. The increase in leakage through all of these fabrics seems to be accounted for primarily by an increase in openness, or in space that must be filled by swelling. The reversal may be partly accounted for by differences in swelling capacity of mature and immature cotton after finishing (Part V).

Such opening of fabric structure might be due to stretching during finishing but, actually, the cloth shrank in width during the wet processing and was finished at the new width. Some of the fabrics were stretched somewhat in length. but changes in dimensions alone did not make the fabrics more open in texture, as will be shown below.

The increased openness of texture can be most reasonably accounted for by the loss of noncellulosic constituents, incident to finishing (Part IV), and especially the much larger loss from the immature cotton owing to the much larger amounts originally present. Evidence of two types will be presented for this view. The first line of evidence is somewhat hypothetical, as it is based on the different amounts of noncellulosic constituents in two cottons of very different maturities, and the presumed behavior of these constituents during the scouring step of finishing. The second is more "practical," as it is based on observed changes in weights per square yard during finishing. Results by the two methods of estimation are in good agreement.

Removal of Noncellulosic Constituents. The relative amounts removed by scouring can be inferred from analytical data (20) from the two very different raw cottons shown in Table VIII.

It is assumed that the analyses would be the same for grey fabrics as for the corresponding raw cottons, and that the values given are representative of cottons with 45 to 50% difference in maturity. Then the materials removed by scouring should include practically all of the pectin, protein, and water-soluble constituents, a large part of the ash, and a smaller proportion of the wax. Probably the water-soluble portion does not include any great amount of the other constituents given. If the noncellulosic materials are taken out in about the same proportions as originally present in the 2 cottons, twice as much would be removed from the immature cotton, or posibly 4% more.

The 2 cottons used for the exploratory fabrics, Nos. 37 and 39, were described above; and the performance of these fabrics was consistent with the inferences drawn from the chemical analyses. Similar large differences in the amounts scoured out can be assumed for any cottons which differ as greatly in maturity.

Losses of Weight. The fabrics made from the Deltapine and "Sike" cottons of 85% and 30% maturity, respectively, were the most suitable for the estimation of losses in finishing. The pertinent data (Table VI) showed that the fabrics of mature cotton, with one exception, finished slightly above the original grey weights, and the fabrics of immature cotton appreciably below.

Losses of weight in finishing are considered to be due mainly to scouring and can be judged by weights per square yard if there have not been changes of weight due to other causes. Possible increases in weight due to the addition of dyes and water repellency agent were assumed to be equal in fabrics being compared; and possible slight differences in moisture regains were not taken into account.

The other important causes of changes in weights per square yard is change in dimensions during finishing, which can be calculated from changes in the number of ends and picks per inch. The number of warp ends per inch increases in accordance with the amount of shrinkage in width, and the number of filling picks per inch decreases in accordance with any stretch in length during finishing. Since all of the fabrics under consideration would have gained in weight as a result of changes in dimensions, the "theoretical" gains were calculated. The observed weights after finishing were all lower than the calculated weights, and the losses in weight due to finishing were estimated.

Four fabrics of mature cotton which had a small net gain in weight, had a calculated average loss on finishing of 1.9%. The corresponding 4 fabrics of immature cotton lost amounts equal to the theoretical gains plus the observed losses, or an average total of 6.3%. Hence the fabrics of immature cotton lost 4.4% more weight than the others, which no doubt accounts in large part for their greater increase in air permeability as well as other effects of

more open texture. The 4.4% is in good agreement with the 4% calculated above from the chemical analyses, considering the necessarily rough nature of both estimates.

It was concluded that any advantage which might be gained from the fineness of a highly immature cotton in the establishment of a finer capillary system in a fabric of given volume might be largely offset by its greater loss of noncellulosic constituents and the corresponding increase in openness of texture.

CONTRIBUTION OF SWELLING

The significance of swelling for the experimental fabrics of this study is to be taken up in Part V, but the most apparent effects of swelling in the fabrics just described will be pointed out now. In special tests, prewetted samples, which were supposed to have approached their maximum degree of swelling, were found to allow the passage of more water at a given head than ordinary air-dry samples of the same fabrics. Such fabrics would seem to be not properly designated as swelling type.

While it may or may not seem logical to compare amounts of leakage through fabrics dry and preswollen, a few leakages under both conditions are shown in Table IX. The fabrics include those of lowest, middle, and highest numbers of picks per inch, made from the cottons of 85%, 30%, and 74% maturities. The preswollen samples whether grey or finished leaked more, roughly up to 10 or 20 times as much as the corresponding samples tested air-dry, with 2 important exceptions. These were the fabrics of immature cotton of middle and highest pickage (Nos. 121 and 123), which, after finishing, leaked less preswollen than dry, and thus showed evidence of some closing by swelling. They were not, however, of swelling type. In fact, only one (No. 105) of the finished fabrics in the table leaked so little as to be considered a swelling-type fabric.

The Table (IX) includes data on leakage of fabrics after scouring. Scouring is taken up in more detail under effects of finishing (Part IV) for a different group of fabrics. While scouring ought to favor swelling, no such effect is clearly evident because scouring opened the texture and increased the leakage through every fabric whether tested air-dry or preswollen. However, the leakage at this point in finishing probably gives a good idea of intrinsic swelling and closing capacities of fabrics, because they are then more nearly free from effects of repellency or of retained air than at any other time during manufacture or finishing. The improvement with increase in number of picks is easily seen for each cotton; also some improvement is seen through the use of immature cotton, in spite of the loss of more noncellulosic constituents. The greater swelling capacity of immature cotton indicated by the centrifuge method appears to be confirmed.

Since an intrinsic better closing capacity of very immature cotton failed to come into full effect in finished fabrics, attention is called again to a possible advantage of cotton which is not particularly mature or highly immature, although relatively fine. The finished plain-weave fabric of cotton of 74% maturity, No. 101, was slightly more water resistant than the comparable fabric, No. 113, of cotton of 85% maturity (Table V). There was an earlier similar example in Part II, but no general conclusion can be drawn from the few available observations.

PROPERTIES OF FABRICS OF NEW CONSTRUCTIONS

The insertion of unusually large numbers of picks per inch resulted in virtually new fabric constructions. Several different cottons were each used in a series of fabrics in which the one variable of picks per inch was changed. This resulted in the changing of important fabric properties to degrees which were found greater than proportional to the progressive increase in number of picks. Some of these changes in physical properties have probably not been observed heretofore, because such fabrics have not been available. They were woven with a special loom attachment for introducing high pickages (21).

Plain Fabrics. The first of these new con-

struction fabrics were in plain weave, Nos. 101 to 105 in Table IV, and were made from cotton of 74% (or average) maturity from yarns described in Table I-B. The numbers of picks ran from 54 to 71, an increase of 17, or 31.5% (18 picks, or 34%, after finishing). The highest number of extra picks made a difference of 1.5 oz. per sq. yd., or 16.7%, in fabric weight (13.6% finished). The warp crimp increased as would be expected, but the cloth thickness showed a quite consistent tendency to decrease by a total through the series of about 4% (3.1% finished). The extreme fabric in the series was thus much more tightly constructed, or more dense, than normal. In the grey it had 16.7% more cotton packed into 4% less volume, as indicated by the 4% less thickness. Bulk densities of some of the fabrics have been studied (Part V).

Warp strength decreased by about 9% as picks increased. Filling strength increased by about 64%, far more than accounted for by the 31.5% extra picks. Presumably the tight packing indicated above, was an important factor in this increased strength. As a result, the series started with the grey cloth of normal pickage appreciably weaker (15%) in the filling than in the warp direction and ended with the filling 52% stronger. The difference was almost as great in the finished fabrics with a change from 23% weaker in the filling of normal pickage to 33% stronger than the warp at the high pickage (Table IV).

Small differences in tear strength (trapezoid) observed across the warps of the finished fabrics seem to have no significance. The tendency to a small gain in filling tear strength with increase in picks may be significant, especially in view of the results with the oxford fabrics, below.

Oxford Fabrics. Comparable oxford fabrics with a great difference in numbers of filling picks were made—Nos. 106 and 107 from the least mature (58%), and Nos. 110 and 111 from the most mature (85%) cottons of the group of three (Table IV). The differences between the normal and high-pickage oxfords were generally similar to those in the plain weave series. The two fabrics of this oxford group with 15 and 16 extra picks in the grey, were thinner by 4.4% and 9.2%, respectively, than the comparable fabrics of normal pickage although 13% or 14% heavier.

Warp breaking strengths went down by 9 to 15%, and filling strengths went up by 33 to 49% with the increase in picks, so that fabrics which were stronger in the warp than in the filling became stronger in the filling than in the warp; a similar relationship held after finishing. Tear strengths of the high pickage oxfords were higher in the filling, by 14 to 26% of the values for fabrics of normal pickage, when they might be expected to be lower.

In 2 other series of 5 fabrics each, made from the cottons of extremes of maturity, 85% and 30%, the numbers of picks were increased in 4 steps. from 56 to 72 or 73 (Table VI) to maxima of 29% or 30% above normal. There were gains in filling strength, again in appreciably greater proportions than the increase in numbers of picks, to maxima of 42%. While the filling strength in each series increased in quite a regular manner, the warp strength did not drop progressively as with the plain weaves, but showed small variations with no particular tendency.

Strengths in the warp direction in the finished goods were lower than in the grey and were about equally erratic. Strengths in the filling direction were all decreased by 10 to 16% by finishing, but the regular increase in strength persisted through the series for each cotton with increase in number of picks. The decrease upon finishing was least for the fabrics of highest pickage, leaving them 54% and 45% stronger than the finished fabrics of lowest pickage of mature and immature cotton, respectively. This was a considerably greater gain than would be accounted for by the added filling threads alone—25 to 27% extra picks in the finished fabric. There were variations of 6 to 12% in the tear strength (trapezoid) across the warps of the finished fabrics, with a tendency downward as the number of picks increased. There were quite regular increases in filling tear strengths in the finished fabrics, up to 25% and 28% through the series.

There was again a tendency, not so consistent as before, for both grey and finished fabrics to decrease in thickness with increase in pickage (and weight), but with no indication of an increase in thickness with extra picks.

EXTREME MATURITY, AND PHYSICAL PROPERTIES OF YARNS AND FABRICS

The use of cottons which differed widely in maturity gave an unusual opportunity to observe differences between yarns, also between fabrics (both grey and finished), due to this variable.

Effects on Yarns. At least two of the cottons were so underdeveloped as to be called bollies, and were used purposely, to represent extreme immaturity. They naturally did not card and spin as well as normal cotton, and gave an abnormally large amount of waste.

Of the yarns (carded) made from the group of cottons of 85%, 74%, and 58% maturities, the warp and filling from the 74% were weaker by 6.7 and 13%, respectively, than those from the most mature (85%) cotton. The warp and filling yarns from the 58% mature cotton were 20% and 13% weaker. Yarns from the cottons of 85% and 74% maturities did not differ in elongation-at-break, but elongations of the yarns made from the cotton of 58% maturity were (unaccountably) lower (Table I-B). Finally, of the yarns made from the last and most extreme cottons covered by this paper, those of 85% and 30% maturity, the warp and filling of the immature cotton were about 1 yarn number finer (3 to 4%) yet were only 13% and 6.7% lower in strength, respectively. Elongations-at-break of the warp and filling yarns from the immature cotton were 30.7% and 21.5% higher, respectively.

The tendency was for highly immature cottons (30% and 44% maturity) to yield yarns that were lower in strength but higher in elongation, than corresponding yarns of mature cotton (85%). It is probable that immature cottons in this range differ greatly and do not follow very definite rules.

Effects on Fabrics. The grey oxford fabric made from extremely immature (44%) cotton, was only 9% and 12% weaker in the warp and filling directions, respectively, than that made from the mature cotton (92%). The elongations in the warp direction in the two fabrics were high and equal. The filling elongations differed, apparently in accordance with the elongations of the yarns.

In the series of fabrics made from the cottons of 85%, 74%, and 58% maturities, those from the less mature cottons were weaker than the fabrics from the most mature cotton. Other comparisons can be made from Table IV.

Comparisons between the Deltapine (85% maturity) and "Sike" (30%) cottons are considered more significant than those above, because 5 fabrics were made from each cotton. The strengths in the warp direction were equal in the corresponding grey fabrics at each of four different pickages (Table VI). In the filling, however, the strengths were lower for the immature cotton in each comparable pair of grey fabrics, by an average of 11%. There were relatively small differences in elongations-at-break and tear strength. The high immaturity of the cotton did not cause the fabrics to be much lower in strength, or to differ greatly in the other physical properties tested.

SUMMARY

Water-resistant fabrics in plain and oxford constructions have been made from cottons of 30 to 92% maturity; some of these fabrics contained up to 31% more picks per inch than can commonly be inserted in such goods. Fabrics in the grey made from very immature cotton were least permeable to air. Some of those with the greater number of picks per inch were so impermeable as to suggest the use of very immature cotton for making goods of moderate weight highly impermeable to air, if they do not have to be finished.

Water resistance of fabrics before finishing showed improvement with immaturity of cotton and with increasing numbers of picks. Water resistance was reduced by finishing, and then some of the fabrics of highest pickage of immature cotton were not as water resistant as corresponding fabrics of mature cotton.

A fabric of high pickage and plain weave, No. 105, made from rather fine cotton of 74% maturity, was the most water resistant of any of the fabrics after finishing. This agrees with other observations which indicate that cottons in the range from immature to average, 70 to 81% maturity, may be best for swelling-type fabrics. Intrinsic fineness may have had an influence on these results, but available data are insufficient to establish this point. Highly immature cottons may be of special interest for swelling-type fabrics which do not have to be finished. They have intrinsic high closing capacity which is largely offset during finishing by loss of noncellulosic constituents and loss of fiber swelling capacity. The contribution of swelling to water resistance does not seem to be very great under ordinary conditions. Of the fabrics of this paper in the grey, Nos. 103, 104, 105, 107, and 111, would probably qualify as of swelling type. Fabrics Nos. 103 and 104 would probably be considered borderline, after finishing; No. 105 was probably of swelling type, finished, but Nos. 107 and 111 were not. However, as mentioned before, there is no accepted definition of the term "swelling type."

The unique fabrics produced showed unusual properties. Fabrics of plain and oxford weaves were increased in filling strength in much greater proportion than would correspond with the number of extra picks inserted. There was the unusual result, also, that fabrics with a relatively large number of additional picks came out thinner, although heavier, than similar fabrics of normal pickage. Tear strengths across the filling were increased with greater numbers of picks even though tighter weaves in general tend to reduce tear strength.

The tendency was toward lower strength and greater elongation in yarns and fabrics made from the most immature cottons tested. There was, however, but little difference in the strengths of some of the products made from very different cottons.

Table 1. *Fiber and yarn properties*

A. Fiber

Fabric number	Variety of cotton	Maturity (caustic soda)	Classer's designation: Grade	Classer's designation: Staple	Fineness (by weight)
		%		in	ug/in
37	Unknown	92	LM to SLM	29/32	5.6
39	Unknown	44	M (Spotted)	13/16	3.6
110, 111, 113	Acala 1517W	85	GM	1-3/16	3.3
101-105	Acala 1517W	74	SM	1-3/32	3.2
106-107	Acala 1517W	58	SLM	1-5/32	2.5
114-118	Deltapine	85	...	1-1/16	4.4
119-123	"Sike" (Unknown)	30	...	1-1/16	2.6

B. Yarn

Fabric number		Yarn number	Twist multiplier: Singles	Twist multiplier: Ply	Breaking tests, single strand: Strength	Breaking tests, single strand: Elongation	Seepages in orifice test
					lb	%	ml/10 min
37	Warp	13.5/2	5.0	5.9	2.8	5.5	11.8
	Filling	13.5/2	4.5	5.9	...	...	...
39	Warp	13.2/2	5.0	5.9	2.3	7.1	1.0
	Filling	13.2/2	4.5	5.9	...	...	...
110, 111, 113	Warp	34.9/2	3.5	4.2	1.5	6.7	5.4
	Filling	21.8/2	3.5	3.8	2.3	7.2	5.1
101-105	Warp	34.8/2	3.5	4.2	1.4	6.7	5.0
	Filling	23.0/2	3.5	3.8	2.0	7.1	5.0
106, 107	Warp	35.2/2	3.5	4.2	1.2	6.2	.7
	Filling	21.7/2	3.5	3.8	2.0	5.9	.5
114-118	Warp	29.6/2	4.6	5.1	1.5	7.5	9.4
	Filling	30.0/2	4.6	3.3	1.5	6.5	10.1
119-123	Warp	30.6/2	4.6	5.1	1.3	9.8	.3
	Filling	31.2/2	4.6	3.3	1.4	7.9	.1

Table II. *Physical properties of Oxford fabrics*

Fabric number	Maturity of cotton	Construction: Warp	Construction: Filling	Weight	Thickness	Breaking tests (strip [1]): Warp Strength	Warp Elongation	Filling Strength	Filling Elongation
	%	ends	picks	oz/ sq yd	in	lb	%	lb	%
A. GREY:									
37	92	76	38	13.5	0.0321	176	42.0	110	9.0
39	44	77	37	13.3	.0329	160	42.0	97	12.0
B. FINISHED:									
37	92	80	34	12.3	...	163	25.6	98	15.3
39	44	80	33	11.9	...	151	24.0	84	16.0

[1] Strip breaks based on thread counts in grey fabric.

Table III. *Air and water resistance of Oxford fabrics*

Fabric number	Maturity of cotton	Air permeability, Permeometer	Hydrostatic pressure	Hydrostatic leakage, prewet samples, 25-cm. head	Bundesmann penetration: Air-dry samples	Bundesmann penetration: Prewet samples
	%	$ft^3/min/ft^2$	head, cm	ml/5 min	ml/20 min	ml/20 min
A. GREY:						
37	92	1.8	62	1675	16.	140.
39	44	1.2	89	196	0.0	5.0
B. FINISHED:						
37	92	1.8	40	1395	.0	108.
39	44	1.1	44	530	.0	36.

Table IV. *Physical properties of fabrics of Oxford and plain weaves (ACALA 1517W)*

Fabric number	Maturity of cotton	Type of Weave	Construction		Weight	Thickness	Warp crimp	Breaking tests (strip)[1]				Total cover factors	Trapezoid tear	
								Warp		Filling				
			Warp	Filling				Strength	Elong.	Strength	Elong.		Warp	Filling
	%		*ends*	*picks*	*oz/sq yd*	*in*	*%*	*lb*	*%*	*lb*	*%*		*lb*	*lb*
A. GREY:														
110	85	Oxford	124	53	9.0	0.0181	18.8	182	29.3	139	11.0	45.7		
111	85	Oxford	126	68	10.3	.0173	24.0	166	36.0	207	12.7	50.8		
113	85	Plain	122	52	8.9	.0176	20.0	154	25.3	125	7.7	45.0		
101	74	Plain	122	54	9.0	.0175	20.4	146	26.0	124	7.7	45.2		
102	74	Plain	122	60	9.6	.0176	25.2	148	29.0	142	7.3	46.9		
103	74	Plain	122	68	10.2	.0168	28.8	135	27.0	191	9.3	49.3		
104	74	Plain	122	69	10.3	.0171	29.2	139	26.7	195	10.0	49.6		
105	74	Plain	122	71	10.5	.0168	30.0	133	27.0	203	9.0	50.2		
106	58	Oxford	124	52	9.0	.0185	17.6	149	25.7	129	10.3	45.4		
107	58	Oxford	124	68	10.2	.0168	22.8	126	28.7	178	11.0	50.2		
B. FINISHED:														
110	85	Oxford	128	53	9.1	.0162	14.4	134	25.0	116	15.0		15.0	5.8
111	85	Oxford	130	67	10.2	.0161	18.0	151	28.7	178	17.0		14.3	7.3
113	85	Plain	123	54	9.0	.0167	20.0	141	26.0	105	9.3		15.5	5.5
101	74	Plain	124	53	8.9	.0164	18.4	139	25.0	107	8.7		15.1	5.0
102	74	Plain	124	60	9.4	.0161	23.6	135	27.7	124	10.0		14.9	5.1
103	74	Plain	122	69	10.0	.0159	26.4	134	27.3	155	10.0		14.3	5.6
104	74	Plain	122	70	10.1	.0160	28.0	133	29.3	167	11.3		13.6	5.4
105	74	Plain	122	71	10.3	.0159	29.2	128	29.7	172	10.7		14.7	5.4
106	58	Oxford	130	51	8.3	.0154	11.2	126	19.7	103	15.3		11.5	5.7
107	58	Oxford	130	66	9.5	.0154	15.2	118	24.7	149	17.7		11.5	6.5

[1] Strip breaks based on thread counts in the grey fabric.

Table V. *Air and water resistance of fabrics of oxford and plain weaves (Acala 1517 W)*

Fabric number	Maturity of cotton	Type of weave	Construction		Air permeability		Hydrostatic pressure	Hydrostatic leakage prewet samples, 86 cm. head	Bundesmann penethration, prewet samples	Rain test, 8-ft. head, sample 6 in. from nozzle
			Warp	Filling	Permeometer	Densometer (time/300 cc.)				
	%		*ends*	*picks*	*$ft^3/min/ft^2$*	*min:sec*	*head, cm*	*ml/5 min*	*ml/20 min*	*gm/20 min*
A. GREY:										
110	85	Oxford	124	53	0.72	11:26	69	364	2.8	5.16
111	85	Oxford	126	68	.21	42:21	113	7.9	.0	.52
113	85	Plain	122	52	.99	8:15	67	656	4.3	Over 10.
101	74	Plain	122	54	.93	10:48	73	382	12	Over 10.
102	74	Plain	122	60	.48	19:24	82	67	0.1	1.68
103	74	Plain	122	68	.0	49:54	143	1.7	.0	.48
104	74	Plain	122	69	.0	53:06	159	.1	.0	.44
105	74	Plain	122	71	.0	58:30	161	.0	.0	.44
106	58	Oxford	124	52	.27	28:38	61	90	.2	1.65
107	58	Oxford	124	68	.0	122:00	123	0.1	.0	.54
B. FINISHED:										
110	85	Oxford	128	53	.87	10:28	51	2449	17	2.89
111	85	Oxford	130	67	.30	30:17	69	122	0.0	.47
113	85	Plain	123	54	.96	7:11	59	2224	20	4.53
101	74	Plain	124	53	.90	8:27	62	1900	14	3.66
102	74	Plain	124	60	.57	13:55	78	476	0.1	.58
103	74	Plain	122	69	.15	29:29	90	27	.0	.36
104	74	Plain	122	70	.18	33:46	93	18	.0	.42
105	74	Plain	122	71	.18	35:28	98	9.2	.0	.35
106	58	Oxford	130	51	.93	9:14	46	2869	8.1	2.39
107	58	Oxford	130	66	.90	10:48	53	339	.0	.98

Table VI. *Physical properties of oxford fabrics*

Fabric number and kind of cotton	Maturity of cotton	Construction		Weight	Thickness	Warp crimp	Breaking tests, (strip)[1]				Total cover factors	Trapezoid tear	
							Warp		Filling				
		Warp	Filling				Strength	Elong.	Strength	Elong.		Warp	Filling
	%	*ends*	*picks*	*oz/sq yd*	*in*	*%*	*lb*	*%*	*lb*	*%*			
A. GREY:													
114 Deltapine	85	124	56	9.3	0.0184	17.6	170	32.0	104	11.3	46.7		
115 Deltapine	85	124	60	9.4	.0176	18.8	158	30.3	113	11.3	47.7		
116 Deltapine	85	124	64	9.7	.0173	18.4	182	32.7	120	12.7	48.8		
117 Deltapine	85	124	68	10.0	.0180	22.0	162	34.3	145	12.7	49.8		
118 Deltapine	85	124	72	10.2	.0171	17.2	176	35.0	148	11.7	50.8		
119 "Sike"	30	124	56	8.8	.0171	15.6	171	28.0	94	12.7	45.9		
120 "Sike"	30	124	60	9.1	.0172	18.0	157	29.0	102	14.0	46.9		
121 "Sike"	30	124	64	9.3	.0179	18.8	168	33.0	108	12.7	47.9		
122 "Sike"	30	124	68	9.4	.0171	21.6	163	34.3	122	12.3	48.9		
123 "Sike"	30	125	73	9.8	.0166	20.0	174	35.0	133	15.3	50.4		
B. FINISHED:													
114 Deltapine	85	128	56	9.4	.0171	14.8	157	27.7	87	14.3		17.3	4.7
115 Deltapine	85	128	60	9.6	.0172	16.0	157	29.7	99	14.7		17.7	4.7
116 Deltapine	85	128	64	9.8	.0170	17.2	161	31.3	106	15.3		16.8	5.1
117 Deltapine	85	128	66	10.1	.0169	17.6	152	31.7	118	15.7		17.0	5.1
118 Deltapine	85	130	70	10.2	.0164	18.0	141	32.0	134	15.7		15.8	6.0
119 "Sike"	30	130	56	8.5	.0155	10.8	139	23.7	83	17.3		15.4	4.9
120 "Sike"	30	130	59	8.8	.0156	11.6	149	25.3	96	18.3		15.8	5.0
121 "Sike"	30	130	63	9.0	.0156	12.4	145	26.7	94	17.0		15.1	5.4
122 "Sike"	30	130	65	9.3	.0155	14.4	144	26.3	107	20.0		14.8	5.3
123 "Sike"	30	130	71	9.5	.0152	15.2	149	28.0	120	20.3		15.1	6.1

[1] Strip breaks based on thread counts in the grey fabric.

Table VII. *Air and water resistance of oxford fabrics*

Fabric number and kind of cotton	Maturity of cotton	Construction		Air permeability		Hydrostatic pressure	Hydrostatic leakage, prewet, 86-cm.head	Bundesmann penetration, prewet	Rain test, 8-ft. head, 6 in. from nozzle
		Warp	Filling	Permeometer	Densometer (time/300cc)				
	%	*ends*	*picks*	*$ft^3/min/ft^2$*	*min:sec*	*head,cm*	*ml/5 min*	*ml/20 min*	*gm/20 min*
A. GREY:									
114 Deltapine	85	124	56	0.87	9:03	65	1173	5.6	Over 10
115 Deltapine	85	124	60	.60	11:22	70	667	1.0	5.09
116 Deltapine	85	124	64	.36	14:23	80	209	0.0	1.73
117 Deltapine	85	124	68	.24	21:34	86	74	.0	.93
118 Deltapine	85	124	72	.09	32:49	95	20	.0	.62
119 "Sike"	30	124	56	.21	36:49	88	29	.0	.82
120 "Sike"	30	124	60	.0	48:00	99	11	.2	.82
121 "Sike"	30	124	64	.0	58:08	108	3.5	.1	.47
122 "Sike"	30	124	68	.0	78:00	114	1.0	.0	.45
123 "Sike"	30	125	73	.0	115:00	116	.1	.0	.32
B. FINISHED:									
114 Deltapine	85	128	56	.87	9:42	55	2186	9.3	2.69
115 Deltapine	85	128	60	.60	12:58	62	1295	5.3	1.03
116 Deltapine	85	128	64	.54	14:35	63	604	.8	.73
117 Deltapine	85	128	66	.45	21:53	68	264	.0	.53
118 Deltapine	85	130	70	.15	28:04	74	126	.0	.45
119 "Sike"	30	130	56	.57	11:24	51	1962	5.2	1.10
120 "Sike"	30	130	59	.60	13:03	51	1024	2.8	.81
121 "Sike"	30	130	63	.57	15:23	52	772	2.4	.66
122 "Sike"	30	130	65	.51	15:23	52	509	.6	.57
123 "Sike"	30	130	71	.57	16:13	53	176	.1	.44

Table IX. *Leakage through air-dry and preswollen fabrics (Suter, 86-cm. head)*

Number and description	Maturity of cotton	Filling picks, per inch	Air dry	Preswollen
	%		ml/5 min	ml/5 min
114 Grey	85	56	177	1173
Scoured		56	1974	1276
Finished		56	259	2186
116 Grey	85	64	21	209
Scoured		64	839	440
Finished		64	28	604
118 Grey	85	72	9.5	20
Scoured		72	201	44
Finished		70	8.5	126
119 Grey	30	56	4.8	29
Scoured		56	1012	473
Finished		56	1609	1962
121 Grey	30	64	0.3	3.5
Scoured		63	588	152
Finished		63	1302	772
123 Grey	30	73	0.1	0.1
Scoured		74	72	17
Finished		71	1456	176
117 Finished	85	66	20	264
105 Finished	74	71	0.1	9.2

Table VIII. *Noncellulosic constituents of mature and immature cottons*

Constituent	92% Maturity	44% Maturity
	%	%
Ash	0.79	1.32
Pectin	.56	1.23
Protein	1.	2.
Water Soluble	2.08	3.05
Wax	.45	1.14
Total	4.88	8.74

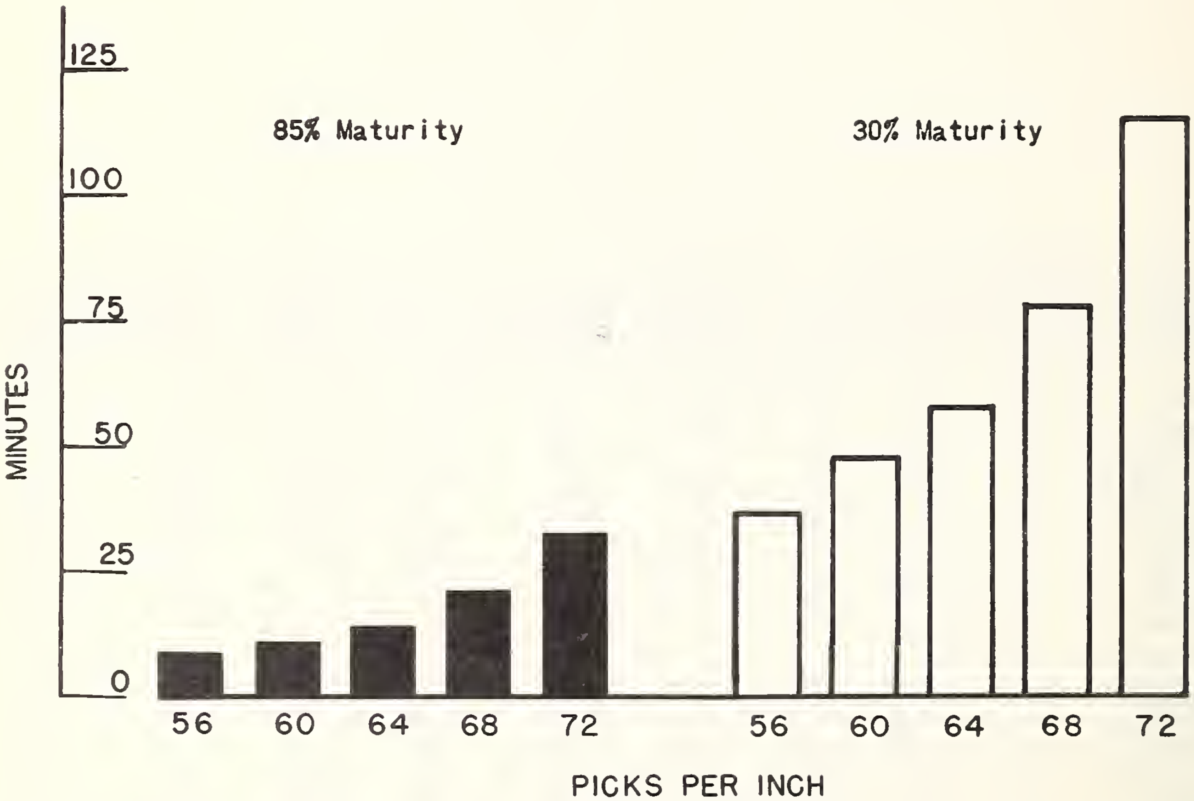

Figure 1. *Permeability to Air (Densometer). Time for flow of 300 cc. of air was greatly increased by the use of very immature cotton and high pickage.*

IV. USE OF FINER COTTONS AND CLOSER WEAVES—EFFECTS OF FINISHING

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INTRODUCTION

Advantage was taken of an opportunity to obtain cottons which had been selected for fineness by an airflow method (28), and to make water-resistant fabrics from them. Fabrics were included of much closer weave than normal, made by the insertion of additional filling picks up to 30% more. These cottons and fabrics have served especially to confirm some of the unusual or unexpected results obtained and reported in other papers of this series. The fabrics were finished in the usual way, as described below, some with modifications of the usual routine, and tested by methods described in Part II.

The second portion of this paper concerns finishing, in general for the purpose of imparting durable water resistance. Immediate effects of finishing have been reported with the discussions of the experimental fabrics.

Although many of the unfinished (grey) fabrics had excellent water resistance, the routine finishing processes detracted from any closing capacity to which swelling might have contributed. Recognition of some causes of deleterious effects of finishing has resulted from observations made at the several main steps in the process, a type of study which has apparently not been reported heretofore.

EXPERIMENTAL FABRICS

Materials Used. Cottons as nearly alike as possible, except for fineness, had been selected and were described as of strict low middling grade, white, and of 1-1/32 inch staple length. They became available as carded yarns, and as raw stock samples. Oxford fabrics were woven from yarn made from each of 3 of the individual cottons—extra coarse (XC), medium, and extra fine (XF); and from each of three blends—75% XC with 25% XF, 50% XC with 50% XF, and 25% XC with 75% XF (Table I).

It is obvious from the table that the fineness was due largely to immaturity and to a minor degree, if at all, to the presence of mature fibers of low perimeter, or "instrinsic" fineness. Estimates of maturity from airflow values were furnished with the cottons (Table I). Micronaire[3] values, their corresponding ratings for fineness, and maturities by the sodium hydroxide method were determined at the Southern Regional Research Laboratory.

The yarns were 30/1 as received; and were plied for use as warp and filling (Table I-B). There were appreciable differences between the sizes of some of the yarns nominally of the same number.

Centrifuge Test on the Yarns. A centrifuge technique (Part V and (37)) has offered a possibility to aid in the selection of cotton for closing capacity. It was tried on the yarns of different fineness and maturity along with the orifice test (35) and is introduced here because it was employed in this way only on the yarns of this paper. Samples of the filling yarns were wetted overnight in water containing 0.1% Deceresol, OT[3] and then centrifuged at 8,000 g.

Water retention increased with the immaturities of the cottons in contrast to seepages in the orifice test, which decreased (Table I). The water retentions observed allowed the prediction that the grey fabrics would increase in water resistance in the approximate order of increasing immaturity of the cottons. The test can thus be used for comparing grey yarns, and no doubt for comparing raw cottons, for use in swelling-type fabrics, but the data obtained do not forecast performance after finishing.

Construction of Fabrics. One fabric was made from each cotton, with the "normal"[1] 52 picks per inch, and one from each cotton with the same warp but with 64 picks per inch, a reasonable maximum for this type of fabric. Only the 2 extreme cottons, extra coarse and extra fine, were woven with still more picks, 68 per inch. This accounted for increases of about 23% and 30%, respectively, in numbers of pick per inch above the normal value.

There were slight differences between fabrics which were intended to be of the same construction owing to small differences in size

[3] Mention of company or trade names is for information and convenience only and does not imply endorsement by the U.S. Department of Agriculture over firms or products not mentioned.

of yarns made from different cottons, and to small differences between thread counts. The grey fabrics of lowest number of picks differed by no more than 1 thread in the total of 177 of warp ends plus filling picks. Those of 64 picks differed at most by 3 in a total of 189. Those of highest pickage were alike. Hence the fabrics within each of the three groups were comparable in construction.

Cover factors were high, from 45 to 49. Weights per square yard (Table II) differed by 5 to 6% within each of the 2 main groups, as might be expected without special adjustments for differences in yarn number, but the differences were not great enough to change any of the conclusions.

Some of the fabrics were of very tight construction as shown by permeability to air (Table III), which decreased greatly through each series of fabrics with fineness of the cottons; and from one group to the next with higher pickage.

Water Resistance. The tests on preswollen fabrics were limited to the Bundesmann apparatus[3], but the regular drop-penetration test was introduced. The water resistance of the best of the grey fabrics was excellent. Even at the normal 52 picks there was pronounced improvement with fineness, easily seen in Table III, in spite of a tendency toward small decreases in weight (Table II). Fabrics were much more effective at 64 picks and, again, there was consistent improvement with fineness. At 68 picks, fabrics of the extreme cottons, extra coarse and extra fine, were both excellent. These observations on the unfinished (grey) fabrics correspond with expectations based on fineness of cotton, and on the results from orifice and centrifuge tests on the yarns.

Since the general effects of finishing seemed to have been established, only 4 representative fabrics were finished, those made from the extra coarse and extra fine cottons in the 52- and the 64-pick groups (Tables II and III). While the effect of fineness is seen in the pair of finished fabrics of ordinary number of picks, 52, its effect almost disappears in the pair of finished fabrics of 64 picks even though the one made from the finest cotton is 5% lighter in weight. In this construction, since either of the extreme cottons would be satisfactory, and of the cottons could be used equally well; and the cottons from immature to average may be preferable to very mature or very immature cottons for swelling-type fabrics, as indicated in Parts II and III.

Swelling, no doubt, contributed to the water resistance attained, and data in Table III, as compared with data in the previous paper, indicate that some of the grey and finished fabrics might have been of swelling type.

The fine-cotton fabrics were much less permeable to air and indicated, again, that fine and immature cottons are favorable to wind resistance in fabrics, whether grey or finished.

PROPERTIES OF THE FABRICS OF NEW CONSTRUCTIONS

These experimental fabrics were of interest also apart from water resistance, because they showed differences in physical properties resulting from the use of cottons of different fineness as rated by airflow; and differences due to the unusual number of picks per inch. The latter proved to be similar to those described for other cottons in the previous paper. Fabric strength in the warp direction tended to decrease with added picks, and filling strength to increase (up to 50%), although the strengths (Table II) within each series were not entirely consistent.

Attention is called again to a pronounced tendency for the fabrics with extra picks to run thinner than those with the normal numbers of picks. This is shown in Table IV by the group-average values of the fabrics of Table II-A; those of 64 picks were considerably heavier, but averaged somewhat thinner than those of 52 picks. Thus, high pickage fabrics were again more dense, for two reasons—more yarn was crowded into the same area, and more into less volume. Both favor resistance to wind and closure by swelling.

The tear strengths (trapezoid) of warp and filling yarns differed, similarly to those of the high pickage fabrics described in Part III. That is, warp tear strength tended slightly downward with the increase in numbers of

picks; filling tear strength increased up to 20% above that of the average for fabrics of ordinary pickage. The tear strengths of fabrics of comparable construction made from the different cottons showed no clear trend with fineness (Table II). Tear strengths were reduced by finishing, but remained better in the filling at high pickage than at normal pickage.

USE OF SPECIAL FABRICS IN WATER BAGS

As a further check on their properties, and on a possible use, several of the fabrics were made into water bags of the same size (11 x 16 in.) as commercial bags used for drinking water. The best bag made was one from the fabric of extra fine cotton, with 65 picks per inch. For comparison with a commercial bag, this bag was filled with water and hung out-of-doors in a test started early on a hot day.

The bag made from the new fabric, with water at 84.5° F., approximately the air temperature, cooled the water about 2° and then held the resulting temperature, 82.5°, for 5 hours while the air temperature rose to 94°. The water remained 5° cooler than that in the commercial bag. The special bag was made from fabric No. 133, which had no finish and weighed only 9-½ oz. per sq. yd. as compared with the 22 oz. of the commercial bag. Neither bag was soaked in water before the test. The commercial bag was made from a tight cotton canvas of ordinary appearance, with some sort of finish. It leaked water but closed off slowly, apparently from swelling.

The result with a high pickage fabric may be of practical interest. The main point brought out is a principle in making a water-holding fabric which may not have been recognized before. At least the action is very different from that of a presoaked bag. Evaporation took place from fiber surfaces or water surfaces within the fabric. There seems thus to be a large evaporating surface, apparently much larger than on the outside of a wet bag. An excellent cooling effect was exerted with much less loss of water than from the commercial bag. It is suggested that this principle be considered for the larger dispensing types of water bag where cooling is desired.

STUDY OF EFFECTS OF FINISHING

The commercial finishing of fabrics of the type and weight under discussion has usually included desizing, some form of open width scouring, mercerizing, dyeing, water repellency treatment, and Sanforizing[3]. The cloth is commonly dried after each step, and may be tentered several times. Most of the finishing at the Southern Regional Research Laboratory was limited, as previously stated, to scouring, dyeing, and treatment with a durable water repellent.

Methods of Finishing. In a representative scour, the fabrics, usually of about 9 oz. per sq. yd., were boiled on a jig for 1 hour in a 2% sodium hydroxide solution; for 2 hours in a second similar solution; rinsed in hot water; boiled for 1 hour in 0.5% soda ash and 0.2% tetrasodium pyrophosphate; washed with hot water and dried on cans. It is well known, of course, that open boiling does not effect complete removal of all the so-called impurities of cotton.

The cloth was dyed on a jig by one of the usual vat-dyeing methods to an olive-drab shade, rinsed, oxidized with dichromate and acetic acid, soaped, etc., as usual for vat dyes. Any possible addition of weight owing to dyeing has had consideration.

To impart water repellency the cloth was padded through a solution of Zelan AP[3] (duPont) at 12% concentration which, at 54% pickup. gave a nominal 6.5% on the goods, but gain of weight was not determined. The cloth was dried on cans without excessive heat and cured at 300° F. for 6 minutes; then run on a jig in a 0.1% solution of soda ash and 0.05% Gardinol LS[3] at 130° F. for 30 minutes; rinsed in hot water, and finally dried on cans. It was not tentered back to width, calendered, or Sanforized.

Effects of Tension and Shrinkage. Among the effects of finishing which are of general occurrence are those from tension and shrinkage. Observations at finishing plants suggested

that a fabric designed and woven with potential self-sealing capacity might be considerably damaged by the usual tension and tentering of routine finishing. Any net gain in fabric area could be expected to make it more open in texture and less easily closed. Checks, however, by means of thread counts on 4 wartime oxford fabrics which had been finished commercially without any special precautions showed that 2 had gained in area and that 2 had lost. Similar checks on other commercial fabrics, described in the section below on mercerizing, showed that 13 out of 15 had lost in area. Hence it seemed that opening of the texture of 9-oz. fabrics by tension in finishing was not a serious problem. High pickage fabrics have greater crimp and greater elongation, shown in tables of this and the previous paper, and might stretch more at ordinary finishing tensions than normal fabrics. Since in some instances the differences were much smaller than in others, this part of the subject should have further investigation.

As a precaution the experimental finishing processes including drying on cans, were all performed at low tension; and the cloth was tentered only once. Hence the fabrics were not stretched in width and, except for the first lot (Part II), were stretched but little in length, as shown by thread counts taken before and after finishing. Rather, there was a little closing from shrinkage in width and, in examples of Table V, a net closing effect from changes in dimensions of 1 to 2.8%. There are changes during finishing other than stretching which cause opening of texture. Increase in interspace through loss of noncellulosic constituents has already been taken up in Part III; and the possibility of opening of fabric texture indirectly from consolidation of the yarn is discussed in Part V, which follows.

TESTS AT DIFFERENT STEPS IN FINISHING

Reduction of swelling capacity of fabrics during finishing often interferes with closing by swelling, while at the same time there develops an increase in the amount of space that must be filled.

Many of the experimental fabrics were tested at the different process steps to bring out directly the effects of finishing on their permeability to air and water. There was great diversity of behavior; and in order to avoid too involved a discussion, the results are shown (Table V) only for some of the fabrics made from cottons considered to be among the most suitable for practical use, with pickages most likely to be of practical interest. Orifice tests on yarns ravelled from the fabrics were included and indicated decreased swelling by consistent progressive increases in seepage. The table shows air permeability at four steps in finishing to be the best simple indication of fabric texture, and leakage of water through preswollen samples as the best indication of any contribution of swelling to closing of fabric. Data for fabrics made from very immature cotton were not included, but three such fabrics were partly covered in Part III (Table IX), where there is a limited discussion of finishing, particularly of effects of scouring.

Changes in thread counts, which should have caused a small net closing effect, appeared upon scouring and persisted at about the same level to the finished fabric. Two exceptions and a few other small variations have no apparent significance with respect to this trend. Although all of these fabrics (Table V) would be considered tight or very tight, they immediately became more open, as shown by increased air permeability, attributable to relatively large losses of noncellulosic constituents.

Final Effects of Finishing. Behavior after repellency treatment represented the summation or final effect of all the finishing processes employed (Table V). The small increase in tightness of each fabric, indicated by thread counts, acted in favor of closing, and air permeability decreased in all fabrics from that observed after scouring. A special analysis of air permeability data with relation to the significance of swelling has been made (Part V).

The leakage of water through each finished fabric tested on the Suter[3] apparatus was greatly increased over that of the corresponding scoured fabric, and was still greater than that of the grey. Two fabrics which were tested only on the Bundesmann[3] apparatus, showed the advantage of increased pickage.

Many additional fabrics were tested at the different steps in finishing, with results "worse" than those shown. The values for the original grey and the final finished fabrics appear in tables of earlier papers.

The results as a whole support the view that finishing, even without opening of the fabrics by stretching, tends to detract from water-stopping capacity, sometimes very greatly. In addition to the observations at different steps in finishing, numerous special tests were made (Part V) by orifice and centrifuge methods. These showed that there was a decrease in swelling capacity of the fibers which contributed substantially to loss of closing capacity of the fabrics.

SPECIAL STUDY OF MERCERIZATION

Goods of the types under discussion are frequently mercerized in finishing. Apparently this is done mainly for better absorption and economy of dye and of water repellency agent; mercerization may contribute to dimensional stability. Kennedy pointed out that finishers seem to persist in this operation (18) although it is really not wanted in military fabrics. The tendency toward luster is undesirable; and Simpson noted that a reduced degree of mercerization would be better when wind resistance is required (33). A reduced degree meant, presumably, the so-called half-mercerization with weaker caustic, which might be expected to minimize some of the effects of the process. Mercerization under tension is well known to increase the openness of texture of many fabrics.

The omission of mercerization in the experimental finishing, in disagreement with general practice, was supported by special experiments. It seems to be widely thought that mercerization of cloth without restraining tension will shrink and thereby close it, but this is not necessarily true; the cloth even though shrunk may become more open. For example, one sample of oxford fabric (Part II, No. 32), not particularly closely woven, was mercerized on a frame without appreciable change of dimensions, and a second sample allowed to shrink freely. The latter shrank by 11.5% and 7.3% in warp and filling, respectively, or 18% in area. The normally mercerized sample was more permeable to air and water in three kinds of tests where it could be compared with the grey (Table VI). The fabric mercerized with shrinkage was also more permeable in two of the tests; that is, it was opened somewhat in comparison with the original unmercerized material, in spite of a considerable reduction in area.

In more practical tests, the same tendency to open upon mercerization was shown by fabrics, described in Part III, which represented low and high maturities of cotton, 30% and 85%, and low and high pickages, 56 and 72 (Table VII). Loomstate fabrics were wet-out on a dye jig at the boil, with water only, then mercerized with 23% caustic on the jig at room temperature. The fabrics were then vat-dyed and Zelan[3] treated. Mercerization alone shrank all of the fabrics by about 3% in area. There were no further changes in dimensions during finishing, but all of the mercerized fabrics were distinctly opened in texture. This was shown by air permeabilities in comparison with both the grey and the normally finished fabrics, with a very few exceptional values. Greater openness was also indicated by leakages through preswollen samples, which were greater for all four fabrics finished than grey, and far greater through the mercerized, finished, low pickage fabrics. Finally, and of more apparent significance, the leakage through both high pickage mercerized fabrics was appreciably less than through those finished without mercerizing. The difference is most logically explained as due to greater swelling and closing capacity of mercerized cotton, already established (Part II).

Mercerization of oxford fabrics under restraint, but without applied tension or stretch, had a generally similar result, with the exceptions noted, to the conventional mercerization of twill and sateen reported by O'Brien and Weiner (24). Their explanation was that the probable rounding and smoothing of the yarn decreased the effective cover and increased the void space through which water could pass

in the hydrostatic and drop penetration tests. Alternatively, one might say that mercerization consolidates the yarn, and increases its density at the expense of its diameter and volume, and thus makes the cloth more open in texture.

In a study of available samples of commercial goods certain suspected changes due to mercerizing were not found. In spite of the tentering, and of the tension during the rest of the process of finishing, representative fabrics of military type showed no increase in area or in openness of texture due to change of dimensions. This was determined by means of thread counts on samples of grey and finished herringbone twill, poplin, and sateen, comprising 1 lot of fabric of each style, portions of which had been finished at 5 different plants. There was no increase in area, but rather a decrease in all but 2 of the 15 finished fabrics.

While mercerization does offer some advantages in the finishing of water-resistant fabrics, it was not generally favorable to closing by swelling. However, experience with two fabrics made from widely different cottons suggests that piece mercerization of very high pickage goods might contribute to effective closing and a highly water-resistant product (Table VII).

USE OF PROCESSED YARNS

It follows from the tendency of fabrics to become more open in texture upon finishing that an improvement could be made by scouring and dyeing the yarn before weaving. Scouring at this stage would enable a tighter fabric to be woven and should thus facilitate closing by swelling. More uniform dyeing throughout the goods would also result. The cloth construction would need to be modified somewhat to compensate for loss of weight of noncellulosic material scoured out. The durable water repellent would be applied in the piece, but the goods could be designed so that any opening of texture would be much less than in normal finishing. Such processing of yarn was not investigated further because of cost and of general impracticability on a large scale.

FINISHING WITHOUT SCOURING

The great loss of closing capacity upon scouring suggested that this step in the process be omitted in the finishing of a few samples even though a boil or scour has been considered essential for satisfactory dyeing. Fabrics were simply wet-out well in water containing a wetting agent, dyed, and treated with Zelan[3] for comparison with goods finished as usual (Table VIII). Comparable fabrics, finished normally and finished without scouring, did not differ significantly in construction. The finished fabrics not scoured were less permeable to air, and were much less permeable to water when tested preswollen. Comparisons made after dyeing (before Zelan treatment) also showed the unscoured fabrics to be superior in these two tests (data not shown in table). After finishing, the unscoured fabrics were also more water resistant in the rain and drop penetration tests (data not shown).

The opening up of fabrics by removal of noncellulosic constituents by scouring has thus been demonstrated by direct tests. If these constituents were left in the goods, there would be a distinct gain in closing capacity by swelling. These results are reported for their bearing on the effects of finishing. Noncellulosic materials left in such goods might be gradually lost in repeated laundering with loss of water resistance. Such a departure from practice as the omission of scouring before dyeing could not be followed unless shown to be permissible by larger scale practical trials and service tests.

TESTS ON WEATHERING

Durability of the finish was not included as part of the main problem but a few observations were made on the effect of weathering on permeability to air and water. Representative finished fabrics were fastened over glass desiccators in place of the covers, tilted to avoid rain standing on them, and exposed outdoors in New Orleans. The exposure of some of the samples was continued up to a year, until the fabrics had greatly deteriorated.

They would not have been serviceable at the end of the test because of rotting and loss of strength. While few of them retained a high proportion of their resistance in laboratory tests for penetration by either air or water, they had not leaked water in heavy rain.

There was rainfall of 37 inches in the first 8 months, and 45 inches in the 1-year period, but there was practically no leakage through the fabrics into the desiccators. For example, 3 inches of rain fell in 2 days after a period of exposure of 10 months and the leakages through pieces of cloth 10-¼ inches in diameter were from zero to only 5 ml. The finished fabrics selected were still very resistant to penetration by rain after severe weathering.

SUMMARY

Cottons selected for fineness by an airflow method differed from 84 to 56% maturity, and from 5.7 to 3 in Micronaire fineness. Oxford fabrics with 52 picks per inch were made from each cotton; also comparable fabrics with 64 to 65 picks per inch, and 2 with 68 picks.

Physical properties of resulting unusual yarns and fabrics, as influenced by fineness and picks per inch, are reported. Results obtained earlier with fabrics of extra high pickage were confirmed. There was a tendency for the strength in the warp to decrease with the insertion of more picks, but to increase in the filling up to 50%, much more than proportional to the numbers of added picks. Tear strength across the warp tended slightly downward with extra picks, but increased up to 20% across the filling. The fabrics were progressively thinner, instead of thicker, as picks were added.

Air permeability decreased greatly with both fineness of cotton and added picks, indicating again that selection of cotton as well as construction of fabric can be expected to contribute to wind resistance.

Water resistance of the best of the grey fabrics was excellent and was not changed greatly by finishing. There were consistent differences with fineness in the water resistance of grey fabrics of 64 picks, but after finishing there was no particular advantage due to fineness.

An experimental water bag, not wet on the outside, cooled water more effectively by evaporation from within the fabric than a commercial bag by evaporation from a wet external surface.

A special study was made of finishing because it usually decreased the water resistance of a closely woven fabric. In neither the experimental nor the available commercial fabrics was there sufficient stretching during finishing to decrease water resistance. To the contrary, there was usually a slight closing effect owing to a small net shrinkage in area.

Tests were made on samples of fabrics taken at different steps in finishing, and on yarns ravelled from them. Air permeability was increased by scouring, but then decreased progressively upon dyeing and Zelan treatment. In contrast, while leakage of water through preswollen samples usually increased over that through the grey fabric, it usually increased also from each finishing process to the next. A decrease in swelling capacity from step to step in finishing will be clearly indicated in Part V.

Finishing of fabrics without scouring to remove noncellulosic constituents of the cotton would make them more water resistant.

Special consideration of mercerizing has shown that, while it usually tends to make fabrics more open, and less readily closed, it imparts increased swelling capacity and may contribute to closing by swelling of a very tight high pickage fabric.

It can be expected that cotton which is intrinsically fine, and does not have excessive amounts of noncellulosic constituents owing to a high proportion of immature fibers, will be favorable to water resistance.

Table I. *Fiber and yarn properties*

A. FIBER

Fabric number	Degree of fineness	Maturity (caustic soda)	Fineness	(Micronaire)	Permeameter	
					Range	Maturity
		%	units	rating	cm	%
130, 131, 146	100% XC (see test)	84	5.7	Coarse	23 and up	83
138, 139	75% XC:25% XF	77	4.6	Average	18 -- 22	75 -- 82
140, 141	100% Medium	79	4.0	Average	13 -- 17	65 -- 74
134, 135	50% XC:50% XF	69	4.0	Average	13 -- 17	65 -- 74
136, 137	25% XC:75% XF	64	3.3	Fine	9 -- 12	55 -- 64
132, 133, 147	100% XF	56	3.0	Fine	8 and below	45 -- 54

B. YARN

Number	Degree of fineness	Yarn number	Twist multiplier		Breaking tests, single strand		Seepages in orifice test [1]	Centrifuge retention
			Singles	Ply	Strength	Elongation		
					lb	%	ml/10 min	%
130, 131, 146	100% XC	Warp 30.0/2	4.6	5.1	1.3	6.6	...	...
		Filling 30.2/2	4.6	3.3	1.2	6.3	14.6	34.2
138, 139	75% XC:25% XF	Warp 30.4/2	4.6	5.1	1.3	6.5	...	...
		Filling 31.2/2	4.6	3.3	1.2	5.2	9.1	35.6
140, 141	100% Medium	Warp 30.4/2	4.6	5.1	1.3	7.8	...	...
		Filling 31.2/2	4.6	3.3	1.3	6.2	7.2	35.5
134, 135	50% XC:50% XF	Warp 29.8/2	4.6	5.1	1.3	6.9	...	...
		Filling 30.2/2	4.6	3.3	1.2	5.0	5.9	37.6
136, 137	25% XC:75% XF	Warp 30.8/2	4.6	5.1	1.3	7.0	...	...
		Filling 31.4/2	4.6	3.3	1.2	5.2	3.9	38.9
132, 133, 147	100% XF	Warp 31.2/2	4.6	5.1	1.3	6.7	...	...
		Filling 31.0/2	4.6	3.3	1.3	5.5	2.4	40.7

[1] Orifice tests made on 30/1 yarns.

Table II. *Physical properties of oxford fabrics*

Fabric number	Degree of fineness	Construction		Weight	Thickness	Warp crimp	Breaking tests (strip) [1]				Trapezoid tear test	
							Warp		Filling			
		Warp	Filling				Strength	Elong.	Strength	Elong.	Warp	Filling
		ends	picks	oz/sq yd	in	%	lb	%	lb	%	lb	lb
A. LOOM-STATE:												
130	100% XC	124	52	9.0	0.0191	15.6	172	27.8	80	10.2	23.6	5.3
138	75% XC:25% XF	124	53	8.9	.0186	13.8	177	28.0	81	10.7	21.4	5.2
140	100% Medium	125	52	8.7	.0179	12.6	177	26.0	89	12.7	22.4	5.3
134	50% XC:50% XF	124	52	9.2	.0191	16.0	171	29.8	88	10.2	24.3	5.4
136	25% XC:75% XF	124	53	9.0	.0190	14.9	175	29.3	90	12.0	22.4	5.3
132	100% XF	125	52	8.5	.0185	15.6	169	28.2	78	9.9	22.5	4.7
131	100% XC	124	64	9.8	.0183	18.4	162	29.2	115	12.1	21.7	5.7
139	75% XC:25% XF	126	65	9.7	.0176	17.3	169	30.7	116	13.3	20.0	5.6
141	100% Medium	125	65	9.6	.0180	18.9	163	33.0	122	13.3	21.9	6.1
135	50% XC:50% XF	124	64	9.9	.0189	20.0	154	33.0	117	11.6	23.7	5.8
137	25% XC:75% XF	124	65	9.5	.0173	17.3	161	29.7	113	12.3	20.0	5.7
133	100% XF	124	65	9.4	.0177	18.4	165	29.9	118	12.3	21.6	5.7
146	100% XC	124	68	10.0	.0181	18.4	165	28.7	123	12.8	21.0	6.5
147	100% XF	124	68	9.8	.0179	16.4	149	31.3	123	12.2	22.0	6.5
B. FINISHED:												
130	100% XC	128	52	9.2	.0171	11.4	125	21.7	78	11.3	16.7	4.6
132	100% XF	128	50	8.6	.0158	9.1	143	20.7	77	12.0	16.0	4.5
131	100% XC	128	64	9.8	.0165	14.4	138	27.0	103	13.7	16.3	5.4
133	100% XF	129	63	9.3	.0153	12.4	147	23.7	107	14.3	16.4	5.1

[1] Strip breaks based on thread counts in the grey fabric.

Table III. *Air and water resistance of oxford fabrics*

Fabric number	Degree of fineness	Construction: Warp	Construction: Filling	Air permeability, Densometer (time/300 cc.)	Hydrostatic pressure	Bundesmann penetration: Conditioned samples	Bundesmann penetration: Prewet samples	Rain test 8-ft. head, sample 12 in. from nozzle	Drop penetration
		ends	*picks*	*min:sec*	*head, cm*	*ml/20 min*	*ml/20 min*	*gm/20 min*	*ml/3 hr*
A. LOOM-STATE:									
130	100% XC	124	52	4:31	60	9.9	45	10	338
138	75% XC:25% XF	124	53	7:24	68	.8	16	5.29	153
140	100% Medium	125	52	10:17	78	.0	14	1.12	85
134	50% XC:50% XF	124	52	7:48	70	.6	9.7	.96	107
136	25% XC:75% XF	124	53	12:56	74	.1	9.9	1.08	59
132	100% XF	125	52	11:03	78	.2	12	.67	40
131	100% XC	124	64	14:32	81	.0	0.3	.48	11
139	75% XC:25% XF	126	65	20:42	86	.0	.3	.41	8.8
141	100% Medium	125	65	21:58	103	.0	.3	.44	4.8
135	50% XC:50% XF	124	64	24:45	94	.0	.2	.43	.4
137	25% XC:75% XF	124	65	33:33	99	.0	.0	.42	.0
133	100% XF	124	65	30:40	108	.0	.0	.42	.1
146	100% XC	124	68	24:53	80	.0	.0	.38	.4
147	100% XF	124	68	51:54	114	.0	.0	.36	.0
B. FINISHED:									
130	100% XC	128	52	6:32	50	.0	44	.73	87
132	100% XF	128	50	11:05	51	.0	11	.50	9.0
131	100% XC	128	64	15:54	61	.0	2.7	.46	.2
133	100% XF	129	63	21:37	62	.0	.8	.41	.0

Table IV. *Fabrics heavier but thinner with higher pickage*

Number of picks	Average wt./sq. yd.	Average thickness
	oz	*in*
52-53	8.83	0.0187
64-65	9.65	.0180
68	9.9	.0180

Table V. *Effects of finishing processes on air and water resistance*

Fabric [1] number	Maturity of cotton	Construction: Warp	Construction: Filling	Air permeability: Permeometer	Air permeability: Densometer (time/300 cc.)	Hydrostatic pressure	Hydrostatic leakage, prewet samples, 86-cm. head	Bundesmann peenetration, prewet samples	Seepages in orifice test
	%	*ends*	*picks*	*ft³/min/ft²*	*min:sec*	*head, cm*	*ml/5 min*	*ml/20 min*	*ml/10 min*
124G	91	124	54	0.66	10:48	70	741	3.3	10.4
S		128	53	.93	6:54	21	1690	...	18.9
D		129	53	.96	8:17	18	1757	...	25.2
F		130	53	.78	8:02	57	2839	17	24.6
127G	80	125	53	.33	16:16	79	397	2.7	5.4
S		130	53	.87	8:11	15	1004	...	8.8
D		130	53	.75	9:38	13	953	...	13.5
F		130	52	.66	11:04	61	3245	11	15.6
110G	85	124	53	.72	11:26	69	364	2.8	9.0
S		128	51	.99	6:44	21	897	...	15.9
D		130	51	.93	7:15	18	1945	...	19.9
F		128	53	.87	10:28	51	2449	17	19.9
111G	85	126	68	.21	42:21	113	7.9	0.0	..
S		130	67	.60	15:25	22	61	...	...
D		130	65	.30	21:34	23	126	...	...
F		130	67	.30	30:17	69	122	.0	..
101F	74	122	54	.93	10:48	73	382	11	5.9
S		122	51	1.26	5:34	15	1033	...	13.2
D		123	51	1.08	6:26	19	1700	...	15.3
F		124	53	.90	8:27	62	1900	14	15.9
102G	74	122	60	.48	19:24	82	67	0.1	...
S		122	59	.78	8:47	23	170	...	...
F		124	60	.57	13:55	78	476	.1	...
114G	85	124	56	0.87	9:03	65	1173	5.6	10.2
S		128	56	.96	7:43	16	1276	...	23.4
D		128	55	.90	7:42	16	1963	...	25.1
F		128	56	.87	9:42	55	2186	9.3	26.0
118G	85	124	72	.09	32:49	95	20	.0	
S		129	72	.24	24:29	23	44	...	Drop
D		130	69	.39	23:41	35	173	...	penetration
F		130	70	.15	28:04	74	126	.0	*ml/3 hr*
130G	84	124	52	...	4:31	60	...	45	338
S		128	52	...	4:21	32	...	69	380
D		128	52	...	4:39	27	...	70	329
F		128	52	...	6:32	50	...	44	87
131G	84	124	64	...	14:32	81	195	0.3	11
S		128	64	...	13:19	31	...	3.8	64
D		128	64	...	15:22	31	...	2.9	53
F		128	64	...	15:54	61	399	2.7	0.2

[1] G stands for grey, S for scoured, D for dyed, and F for finished.

Table VI. *Effect of mercerization on permeability of an Oxford fabric*

Description of fabric	Air permeability		Penetration through preswollen fabric	
	Frazier	Permeometer	Suter (25-cm. head)	Bundesmann
	ft³/min/ft²	*ft³/min/ft²*	*ml/5 min*	*ml/20 min*
Grey goods (No. 32)	1.5	...	935	69
Normal merc.	3.2	3.4	1980	77
Merc. with 18% shrinkage in area	2.1	2.3	1743	56

Table VII. *Effect of merccrization on air and water permeability*

Fabric number [1]	Maturity of cotton	Construction		Weight	Air permeability		Hydrostatic pressure	Hydrostatic leakage, preswollen, 86-cm. head
		Warp	Filling		Permeometer	Densometer (time/300 cc.)		
	%	*ends*	*picks*	*oz/sq yd*	*ft³/min/ft²*	*min:sec*	*head, cm*	*ml/5 min*
114 G	85	124	56	9.3	0.87	9:03	65	1173
F	85	128	55	9.4	.87	9:42	55	2186
MF	85	130	55	9.5	.93	7:04	38	6222
118 G	85	124	72	10.2	.09	32:49	95	20
F	85	130	70	10.2	.15	28:04	74	126
MF	85	130	70	10.4	.72	24:55	58	47
119 G	30	124	56	8.8	.21	36:49	88	29
F	30	130	56	8.5	.57	11:24	51	1962
MF	30	130	55	8.8	1.11	6:05	32	10947
123 G	30	125	73	9.8	.0	115	116	0.1
F	30	130	71	9.5	.57	16:13	53	176
MF	30	132	71	9.8	.24	25:49	42	95

[1] G stands for grey; F for SRRL finish, not mercerized; and MF for both mercerized and finished, without scouring.

Table VIII. *Improvement in water resistance due to omission of scouring*

Fabric number [1]	Maturity (caustic soda)	Construction		Air permeability		Hydrostatic leakage, prewet samples, 86-cm. head
		Warp	Filling	Permeometer	Densometer (time 300 cc.)	
	%	*ends*	*picks*	*ft³/min/ft²*	*min:sec*	*ml/5 min*
117F	85	128	66	0.45	21:53	264
117NS		130	67	.09	26:13	94
112F	30	130	65	.51	15:23	509
122NS		130	67	.0	50:19	9.5
						Bundesmann [2]
130F	84	128	52	...	6:32	44
130NS		128	51	...	6:36	29
132F	56	128	50	...	11:05	11
132NS		128	51	...	12:47	5.3
131F	84	128	64	...	15:54	2.7
131NS		128	63	...	17:11	1.6
133F	56	129	63	...	21:37	.8
133NS		128	64	...	29:57	.2

[1] F stands for usual finish, including scouring; NS for not scoured.
[2] Ml./20 min. through prewet samples.

V. SIGNIFICANCE OF SWELLING

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INTRODUCTION

The swelling of fibers in tightly woven water-resistant cotton fabrics is a factor in their resistance to the passage of water upon wetting, but numerous observations (Parts II, III, and IV) have led to the view that such swelling contributes to water resistance to an important degree only under especially favorable conditions.

Since there is no practicable method for the direct measurement of the contribution of the swelling of fibers to the closing of a fabric, evidence regarding the significance of swelling has been obtained from special tests by orifice, centrifuge, and hydrostatic methods on many of the yarns and fabrics of this investigation. Swelling seems frequently to be supplemented by another factor which may give the effect of closing by swelling. This is interpreted as something beyond the usual water repellency effect, involving air firmly held during swelling under certain conditions. This factor apparently helps block the passage of water. It may come into practical effect during the wearing of water-repellent garments.

This paper is concerned principally with what happens during finishing to detract from closing capacity; viz, with opening or loosening of fabric texture and with reduction of swelling capacity of the cotton.

OPENING OF FABRIC TEXTURE DURING FINISHING

It is shown in earlier papers that more water may be transmitted through preswollen fabrics after than before finishing, partly from opening of fabric texture and consequent increased difficulty of closing by swelling. Loss of noncellulosic constituents alone was shown to account for an opening effect at the scouring step in finishing, differing in degree with the maturity of the cotton (Parts III and IV). Texture could obviously be opened by stretching in finishing but in the measurements of most of the experimental fabrics no significant increase in area has been found. Observations on samples taken at different steps in finishing, however, have shown changes in permeability to air or water, owing to changes in fabric texture from other causes.

One suspected cause of opening of texture, a possible consolidating effect on the yarn in a fabric during finishing, remains to be taken up. Tension, which is common to all finishing processes, might seem to consolidate warp yarns by the exertion of lateral pressure when cloth is pulled against twist and crimp. Tentering with tension widthwise might seem to do the same thing to the filling yarn; and, even without tentering, tension in the warp direction would cause pressure also on the filling and might tend to consolidate it. Then there would be the added effect of pressure as wet goods are rolled and unrolled time after time on the jig; and as the cloth passes through the nip of a padder. If the constituent yarns were thus being consolidated without any change in fabric area, decreases in densities in interyarn regions might also seem to result, which would make the fabric more open, as it is after mercerization (Part IV). This possibility of consolidation was studied by novel methods, but found not significant. The methods are described below, however, since they help to show some of the differences in fabrics due to properties of different cottons, and differences in effects of weaving, as well as changes within fabrics during finishing.

Evidence from Airflow. The problem of changes in the capillary system of fabrics was studied by consideration of the flow of air because, unlike the flow of water, it does not depend upon the uncertain factors of difference in wetting of the fabrics or difference in amount of swelling while wet. Data on permeability of many fabrics by both air and water have been so consistent as to indicate that the consideration of the systems is not seriously complicated by accidental large pores through the fabrics.

In flow methods such as those using the Permeometer[4] and the Densometer[4] it may logically be assumed that effects of finishing treatments on water-cotton relationships are

[4] Mention of company or trade names is for information and convenience only and does not imply endorsement by the U. S. Department of Agriculture over firms or products not mentioned.

secondary to the simply considered mechanical system of pores in the fabrics. One may further assume that pore shapes in the various fabrics described in these papers are similar, because, in the absence of any drastic treatment like mercerization, the capillary system in a yarn or in a fabric will likely remain essentially the same except in pore size all through the different finishing processes, as far as may be determined by numbers, shapes, and sizes of fibers. Then, the variations brought about by finishing in rate of airflow as measured by the Permeometer and the Densometer should be equivalent on the same fabrics. The validity of this assumption is borne out both by the significant correlation of Permeometer readings with the reciprocal of Densometer readings, and by the great similarity between the effects of scouring, dyeing, and finishing as shown by the values obtained by the two methods.

The mean effect of scouring greyfabrics was to increase the air permeability by the factor of 1.86 (by Densometer, 1.83; by Permeometer, 1.88). The dyeing step reduced the permeability to 1.49 (by Densometer, 1.54; by Permeometer, 1.44), with the permeability of the grey fabric still taken as unity. The Zelan[4] treatment brought about a further reduction to 1.30 (by Densometer, 1.26; by Permeometer, 1.33). Thus increases in permeability were observed for the scouring step in which solids were removed and the porous system logically enlarged, while decreases in permeability were observed for both the dyeing and Zelan steps in which solids were added and the porous system logically reduced. The magnitude of such changes may be roughly evaluated from Poiseuille's law of capillary flow, because the systems probably remain essentially the same at steps in finishing except in size of capillaries. An increase in the flow in the ratio of 1 to 1.86 corresponds to an increase of 17% in the mean effective radius of the pores, in the conditioned fabrics, if the flow has increased as the 4th power of the radius. Similarly, the relative values of 1.49 after dyeing and 1.3 after finishing correspond to average radii of capillaries about 10% and 7% greater, respectively, than in the original grey goods. In the absence of any other known contributing cause, the effect is that of dyeing and of Zelan treatment replacing part of the loss from scouring.

These considerations do not indicate progressive increase in openness of structure such as might be due to consolidation of yarn during finishing but, rather, closing of the fabric structure after scouring. Effects of these changes in texture do not, however, appear in tests for leakage of water through preswollen samples representing the different steps in finishing. Rather, there is the progressive increase in leakage which might still seem due to increasing openness of fabric texture, were it not, as will appear later, due largely to decreasing swelling capacity.

Evidence from Orifice Tests. Samples of yarn which represent different stages of finishing of any given fabric are regarded as closely comparable, when used in orifice tests (35; and below); and seepage of water through such samples showed a relatively large progressive increase (Table I; and Part IV, Table V). The first example tested in this way (Table I) was a fabric finished commercially from which filling yarns were taken at different steps. Orifice tests on the grey yarn yielded about the usual value for a mature, somewhat coarse cotton, 11 ml. in 10 minutes; but after finishing including water repellency teatment, the seepage was nearly 3 times as great, 29 ml. In the second example, seepages are shown for filling yarns from an experimental fabric (Part II), grey and at three steps in finishing. The general behavior was the same, a gradual large seepage increase, although the fabric was made from a different cotton and showed different values from the first.

In contrast, orifice tests with the nonswelling liquid dioxane (Table I) showed six times as much seepage as of water through the grey yarn from the first fabric, mainly because there was no swelling. There was an appreciable increase in seepage through the yarn from the fabric which was scoured, but it seems clear from this experiment and the others with nonswelling liquids, whether dioxane or methyl amylketone, that there was a tendency for the seepage to remain at the new level rather than to continue to increase from step to step in finishing, as with water. The failure of seepage to continue to increase with nonswelling liquids indicates that there was not any considerable progressive consolidation of yarns with an accompanying tendency toward more open

spaces between yarns in the orifice (see Special Methods, below). Then, with water also, this factor could not have contributed, unless possibly at the scouring step, to the progressive increase in seepage with finishing. The latter increase must, rather, have been due mainly to a progressive decrease in swelling capacity of the cotton from step to step in finishing.

REDUCTION OF SWELLING CAPACITY

The process in finishing which might seem most likely to affect swelling is drying. However, although it is repeated a number of times, its effect proved to be small. This effect was tested by repeated wetting and drying of grey yarn, 5 times at 220° F. for 30 minutes each, plus 1 simulated cure at 285° F. for 5 minutes. Seepage in the orifice test was increased by such drying by only 1.2 ml., from 11.4 to 12.6, which was much less than the usual increase for yarns taken from grey to finished fabrics (Table I). Hence, repeated drying was concluded not to be the key factor in the decrease in swelling capacity of cotton during finishing.

Scouring of the experimental fabrics caused reduction in, swelling capacity. The less effective closing is attributed to decrease in swelling, because maximum possible swelling of any such material as those tested, under the prevailing conditions, should have occurred in the water used in the orifice tests. It contained the usual wetting agent, and yarns with all treatments usually wet very readily in such solutions.

In agreement with these early observations, all scoured yarns and yarns from scoured fabrics that were tested, whether made from mature or immature cotton, showed more seepage through the scoured than through grey yarn. This represents a lower degree of swelling, as is indicated also by centrifuge tests on similar yarns taken from grey and scoured fabrics (Table II).

Dyeing might appear not to have much additional effect to decrease swelling capacity, but greater seepage through dyed yarn in orifice tests and decreased swelling as indicated by the centrifuge method both point to a further reduction of swelling.

The water repellency treatment might be expected to have an adverse effect, because there is somewhat less regain in cotton exposed to a humid atmosphere after a repellency treatment than before (16, p. 59). This implies lower swelling capacity, which was indicated by orifice and centrifuge tests.

The most convincing evidence of differences between cottons in swelling capacity, and of reduction of swelling by finishing, has been furnished by the centrifuge method.

Swelling Capacities of Cottons. Estimates of swelling capacity by the centrifuge method for the cottons of 85% and 30% maturity in the form of yarn (Table II) were about 52% and 73%, respectively; and the observed retentions showed that the raw cottons would have practically the same values for swelling. These values are higher than reported for cottons as determined by some other methods. High values are supported, however, by Ashpole (6) who determined the saturation regain of a sample of cotton of unknown maturity as 43%. If this regain actually had consisted only of water of swelling, the swelling by volume would have been 69%, this figure being based on a specific volume of 0.621, which corresponds to a density of 1.61 for cotton, as determined in water (17, p. 95). A level of swelling nearly as high is indicated by Dorkin and Chamberlain (10), who reported retention of water within the fiber upon centrifuging as 40%, exclusive of capillary water. This retention (regain) considered as additive in volume on the basis just given, corresponds with a swelling of 64.4% (see below, Centrifuge Technique).

The validity of such high values for swelling of raw or grey cottons is also supported by consideration of the orifice test (Part I).

The great difference between the cottons of 85% and 30% maturity in estimated swelling capacity immediately raises the question why the extra 20% estimated swelling of immature cotton did not impart effective permanent closing capacity and make the fabric of immature cotton definitely superior in water resistance. There are at least two apparent reasons. Undoubtedly, the greatest adverse influence is

the much greater loss of swelling capacity of the immature cotton during finishing. Swelling capacities calculated from average values of intercepts (see Centrifuge Technique) for yarns from two fabrics of each cotton show progressive large decreases from step to step in finishing. Most notable, however, was the much greater loss by the immature cotton, which finished with only 5% greater apparent swelling capacity than the mature cotton (Table II).

The value of even this extra 5% swelling is not realized in cloth because at least 4 to 5% more noncellulosic material is removed from the immature than from the mature cotton in scouring (Part III), and we can surmise that the extra space thus left in the immature cotton to be filled by swelling would take up its extra swelling capacity. That is, the considerations above account very well for the general observations on finishing, particularly those in Part III. There the immature-cotton fabrics were better than the mature in the grey in both air and water permeability. The fabrics of neither group were as good after finishing as before, and some immature-cotton fabrics were worse in some tests than the corresponding mature-cotton fabrics. In these (Part III) cases any contribution of greater fineness of the immature cotton to the closing of the fabrics did not offset the unfavorable factors.

Evidence from Hydrostatic Tests. The conventional hydrostatic test was applied to fabrics at different steps in finishing (Part IV, Table V). The hydrostatic heads required to cause the 3 drops leakage through the 10 selected experimental fabrics were from 60 to 113 cm. in the grey, and appreciably lower in every case in the finished goods, 51 to 78 cm. The values for fabrics at the intermediate steps, after scouring and after dyeing, were much lower, usually about equal for each fabric, at 13 to 35 cm. Any effect of swelling was obscured by some degree of water repellency and slowness of wetting, so no conclusions regarding swelling could be drawn.

On the other hand, the leakage through samples taken at the different steps in finishing, preswollen, and tested under the fixed head of 86 cm. was progressively greater, and frequently very large, in 8 of the 10 fabrics. The evidence indicated decreased swelling capacity during finishing and little contribution of swelling to closing. This was not shown as clearly, however, as in orifice and centrifuge tests on weighed samples of yarn, with its freedom from fabric variables.

While the hydrostatic evidence points so far to a decrease in closing capacity and in water resistance during finishing as far as swelling is concerned, other hydrostatic tests have brought out another influence which tends to add to water resistance. This influence is discussed immediately below.

ENTRAPPED AIR AS A FACTOR IN WATER RESISTANCE

The presence of entrapped air has already been mentioned as contributing appreciably to the water resistance of a tight fabric preswollen under suitable conditions, in a way believed not due merely to the usual water repellency. This was brought out especially well by a number of hydrostatic tests in the Suter[4] apparatus, of samples prewetted and preswollen in different ways (Table III). Typical finished, high-pickage fabrics, No. 117 made from cotton of 85% maturity (Part III) and No. 131 from cotton of 84% maturity (Part IV), were used. Both had been scoured, dyed, treated with Zelan[4], and washed. In tests of the several types, a given fabric showed leakages of different magnitudes under the constant head of 86 cm. of water.

Control experiments included determinations of head required to cause 3 drops leakage through air-dry samples (regarded as unswollen). The values were similar at 73 and 69 cm. (Table III), respectively, which correspond with good water resistance. In other control or base experiments the amounts of leakage through other similar air-dry samples was observed under the head of 86 cm. (Table III). The resulting values, 17 ml. and 63 ml. in 10 minutes, respectively, fell in an intermediate range.

When similar samples were preswollen according to the 2 methods discussed in Paper II (1. Boiled in water for 10 minutes to wet them thoroughly, then soaked in water for 50 minutes to 24 hours to swell; and 2. soaked at room temperature under 100 cm. head of water for

24 hours), there were much greater leakages, 115 and 480 ml., respectively, in 10 minutes. These samples were supposedly free from entrapped air and well swollen, but leaked much more than air-dry samples, indicating that the low leakage of the latter was not due mainly to closure by swelling.

Samples (Expt. 4) were prepared by holding for only 1 hour under water at a head of 100 cm. and were then found to leak in the lowest range. These samples were superficially wet but held only 19.3% water after light blotting, much less than the thoroughly wetted fabrics (Expts. 3, 5, and 6). They had extremely low leakage, however, compared with samples soaked for 24 hours (Expt. 3). As judged by both regain and length of time of soaking, the 1-hour samples would not have been as greatly swollen. On the other hand, they leaked much less than the samples (Expts. 1 and 7) which obviously depended mainly on water repellency. The estimated swelling of the 1-hour sample (Expt. 4) would be 31.1%, according to methods discussed below, if the regain were all due to water of swelling. This would be near the maximum for this type of fabric, and is shown later not to be sufficient for closure against passage of water. Hence, there is again evidence of some other factor, possibly entrapped air, not displaced or dissolved, which helps to block the passage of water.

This view is supported by another type of experiment wherein the fabric is exposed to an atmosphere approximately saturated with water vapor before testing for leakage. The original experiment of this type was intended to show whether a sample exposed only to water vapor would attain a degree of swelling comparable to that on immersion in water. The result is reported below with results from similar experiments run following a recent report by Lord (19), which seemed to support the observation that absorption of water vapor by a water-repellent fabric might increase its water resistance. Two such fabrics which had been exposed by Lord above a water surface gained slightly in weight owing to absorption of moisture; after the exposure the fabrics showed hydrostatic heads 10 to 11% higher than before. These observations did not seem to be regarded by that author as having special significance. In order to bring out more clearly a possible relationship with the effects now under discussion, additional samples of the 2 finished fabrics, Nos. 117 and 131, were allowed to stand in a closed container over water for 22 or 24 hours, and then tested. These samples (Table III) increased in regain from 5% or 6% to 15%, and the hydrostatic heads required to start leakage did increase significantly, by 19% and 14.5%, respectively. Also, in addition to requiring abnormally high hydrostatic heads to bring about leakage, samples humifidied by water vapor in further experiments displayed much lower leakage in tests at the fixed head. Much less moisture was absorbed than by soaked samples, and much less than required for complete swelling, but the leakage was extremely low. The swelling was estimated at 24.2%, believed not to be enough to close a fabric. The soaked samples (Expts. 5, 6, and 10) which were supposedly fully swollen leaked far larger amounts of water, which indicates that swelling alone did not account for the low leakages through humidified samples.

As a final check, many of the fabrics were boiled in water for 3 minutes after the tests described and retested under the same head (86 cm.). This length of time may not have been the most favorable to put the fabrics all into a common state, but there were large increases in leakage through all but two. Differences within the last column for either fabrics are of doubtful significance because replicates have often differed as much as in the ranges shown. The leakages are considered as having been equalized for each fabric, however, by removal of air, since all came to the same order of magnitude.

Explanation of Results. The greater resistance of a water-repellent fabric to penetration by water after the absorption of water from the vapor phase must be regarded as a real result and suggestions will be made toward its explanation. The presence of the added moisture absorbed by the fibers might suggest the possibility of easier wetting and penetration, rather than of increased water resistance. On the other hand, swelling of the fibers probably tends to make the capillaries among them smaller and correspondingly more difficult to penetrate. This point will not be pursued further, owing to the absence of information on the wetting or water repellency of fabric con-

taining a durable repellent, and at the same time considerably swollen by high regain such as 15%.

Such results are not readily explained on the basis of water absorption alone unless one could imagine that some particular mode of absorption on the finished cotton surface made that surface more difficult to wet. This seems unlikely. Neither, so far as known, could the presence of a water-repellency agent make the vapor-exposed fabric more repellent than the air-dry sample.

The smallest amounts of leakage do seem explainable on the basis of some particular form of entrapment or retention of air. A somewhat similar phenomenon was observed with cellulosic materials which were not water repellent. Water vapor was taken up by filter paper and bleached cotton cloth in such a way that they seemed resistant to further wetting (11). This effect has not been found described elsewhere, or completely explained, but it appeared to be due to the entrapment or enclosure of air so that the cloth and paper did not wet as readily after exposure to water vapor as when dipped air-dry quickly into water. This effect was not due to air as ordinarily present within the cloth and paper, because when the air-dry materials were dipped quickly into water, air was obviously readily displaced.

Hence, it appears that absorption of water vapor by a fabric could conceivably interfere with subsequent displacement of air and that some relatively large amount of air was present in vapor-swollen fabric, also that it was not displaced by water under a head of 86 cm. and that it contributed to the water resistance in addition to the effect of ordinary repellency.

Practical Implications. It seems possible that a water-repellent fabric may become somewhat swollen by water vapor and actually more water resistant even during an ordinary hydrostatic test while it is standing in the apparatus with one side in contact with water during the short time before penetration takes place. There is no obvious way to make an adjustment or correction for this factor, which may have an effect on hydrostatic test results.

Of more practical interest, tightly constructed water-repellent fabrics should become more water resistant if they should happen to be worn in very humid or foggy weather immediately before being exposed to rain. However, the absorption of water vapor with the attendant effects described can probably take place also under ordinary conditions within the cloth in a garment after the outside has been exposed to rain or has become wet by it. The entrapped air might serve even more effectively as a second line of defense than the swelling of fibers.

BULK DENSITY AND CLOSURE OF FABRICS BY SWELLING

Data on the tightest fabrics that were woven show that closure by swelling is related to bulk density. Consideration of bulk density supports the view already expressed in Part I that closing of a swelling-type fabric must depend upon a plane or a region of maximum density through the center of the piece. Sufficient data from previous papers are presented with bulk densities (Table IV) to show the connection between this property and fabrics that could possibly be rated as of swelling type. The bulk densities were calculated from thickness and weight per square yard in earlier tables.

The volume and swelling considerations are illustrated by one of the fabrics used in various tests discussed above, No. 117. It had a bulk density of 0.8 in the finished state. If the density of cotton in water is taken as 1.61 and the regain of the air-dry cotton is assumed to have been 7% (in all of the experimental fabrics), this fabric contained 46.4% of its volume of cotton (without regain) and 53.6% of air space. The swelling of this fabric upon thorough wetting, as inferred from other fabrics made from the same lot of cotton (Nos. 114 and 118 in Table II), would have been about 30.3%. The cotton, then, could fill by swelling only 61% of the volume of the fabric (see Calculations of Closure of Fabrics). Other test data (Table III) show that this was not a swelling-type fabric, even though it was very water-resistant in some of the tests. It obviously did not swell enough to close off the zone of maximum density. The grey was more water resistant than the finished fabric, and would almost rate as of swelling type (Part III, Table

VII-A). The critical plane must have been nearly closed off even though the bulk density was appreciably lower before finishing (Table IV); and the swelling in fabric form was about 40%, so that only 60% of the fabric volume was filled.

Fabric No. 123 (Part III) made from a cotton of greater swelling capacity could be rated in the grey as of swelling type, from the virtual absence of leakage through preswollen samples. If its constituent cotton had swollen up to its capacity when in yarn form, it would have filled 79.2% of the volume of the fabric. Actually, the swelling in fabric form as determined by the centrifuge was 48.6% and, by calculation, the fabric was swelled to 68.1% of its volume. The region of maximum density had been closed although the fabric as a whole was not sufficiently swollen to fill all of the air space. The same fabric after finishing was of slightly higher bulk density but was not fully closed by swelling. As calculated from the observed swelling of the finished fabric in Table II, the cloth would have been 65% filled by the swollen cotton. There seemed to be a narrow margin of swelling between the grey and finished fabrics which determined closing. The most dense fabric made, with bulk density of 0.87, consisted of about 51% by volume of cotton (without regain).

It will be obvious from various considerations in this and other papers in this series that the estimates of space and swelling within fabrics are only approximations but that their magnitudes are essentially correct.

SPECIAL METHODS

Special applications of orifice and centrifuge tests are described below, also some of the special calculations.

Orifice Test. The orifice test (Part I; and 35) found special application to the study of relative densities of yarns with particular reference to their state in fabrics. Strands of yarn drawn as a group into an orifice tend, no doubt, to form interyarn regions or "channels" that are less dense than the yarns themselves, and it is a reasonable assumption that such regions will be still less dense when the yarns (of equal weight) are more dense. Hence, it may be assumed further that if there are thus larger pores through the capillary system between yarns, water will be transmitted at a greater rate in general accordance with Poiseuille's law, and thus bring about significantly greater seepages. Conversely, greater seepages under suitable comparable conditions in orifice tests should indicate greater relative densities of yarns.

That higher densities in yarns could be thus detected was demonstrated with 30/2 filling yarns from fabrics made from Deltapine and "Sike" cottons (Part III). Routine orifice tests were made on samples of equal weights of each yarn ravelled from fabrics woven with 56 to 73 picks per inch (Table V), both grey and finished. The grey yarns from the mature-cotton fabrics showed a consistent increase in orifice seepage with increase in number of picks per inch. Yarns from the corresponding finished fabrics all had 2 to 3 times as much seepage, and again showed higher values with increased pickage. The yarns of immature cotton from grey fabrics were very low in seepage, which showed a tendency to increase with pickage. Yarns from the finished fabrics of immature cotton had much greater seepages than the equivalent grey yarns, and had also a consistent and relatively large increase with picks per inch.

The data in Table V were confirmed by similar observations for succeeding time periods. Since the samples in each series consisted of equal weights of yarn from the same lot, their swelling should have been the same if unaffected by outside factors. Hence, the increased seepage through yarns from grey fabrics with greater number of picks must be regarded as due to mechanical compression, some of which persisted after ravelling. The much greater seepage through yarn from each fabric after finishing must be attributed very largely to its loss of swelling capacity. Since the finishing processes were all the same, the progressive increase in seepage with more picks, after finishing, must again be due to increased compression and probably more effective setting by finishing at the higher compressions.

It was, therefore, concluded that the orifice test could be used to show relative degrees of compression of yarns taken from fabrics, although progressive compression was decided as not taking place to a significant degree for yarns in fabrics from step to step in the fabric finishing.

Centrifuge Technique. The amounts of water retained upon centrifuging under suitable conditions have been rather generally accepted as a good indication of the relative amounts of swelling of cellulose fibers; but application of the centrifuge as described below has been reported to indicate actual swelling (by weight).

The general method for determinations of water retention was that described by Welo *et al.* (37). Samples of approximately 1 g. each of fiber, yarn, or fabric were wet-out overnight in water containing 0.1% Deceresol OT,[4] then centrifuged for 30 minutes at 8,000 g., or under conditions described below. Amounts of retention, or moisture regains, were calculated on the dry weights of samples.

Data from tests on fabrics and the materials from which they were made, representative of the range of conditions of this investigation, have been assembled in Table II.

The table includes 2 raw cottons of very different maturities, in comparison with 30/2 yarns made from them; and with similar yarns ravelled from fabrics which differed in density as determined by the picks per inch, 56 and 72. Retentions by the two cottons in comparable tests were very different in every case. There was but little difference between the retention by yarns of different densities which came from the fabrics of different pickage made from either cotton.

On the other hand, there were differences between fabrics of different densities. Retentions were lower for fabric than for yarn; and lower for fabric of 72 picks than fabric of 56 picks, evidently owing to tighter construction and greater restriction of swelling. Of most interest, decreases of retention were shown in yarns ravelled from fabrics from step to step in finishing (Table II); and corresponded with progressive decrease of swelling capacity.

Possible differences in wetting, with a resulting effect on retention and swelling, were apparently eliminated by the use of a wetting agent in sufficient quantity to make all samples wet easily.

The most important application of the centrifuge has been for the estimation of amount of swelling according to Preston and Nimkar (30). For this purpose observations of water retentions were made at 2 centrifuge speeds, 7,000 and 10,000 r.p.m. for each sample. The retentions were plotted as regains against the reciprocals of these speeds squared, and a straight line was drawn through the resulting points to intercept the regain axis. This axis corresponds with infinite speed, where unity divided by speed squared equals zero, and where the amount of water held by capillary forces would be zero in this idealized case. Then an intercept on this axis is a measure of the amount of water in the fibers that causes swelling. Percentages of swelling by volume were calculated from the intercept retentions, expressed as regains, which were taken as additive to the volume of cotton that corresponds with its density in water, 1.61 (17, p. 95). At this density its specific volume will be 0.621, so the percentages of regain corresponding with the regain intercepts were divided by 0.621 to obtain the percentages of swelling by volume.

Calculations of Closure of Fabrics. The calculations of percentages of volume, of swelling, and of closure of fabrics, particularly as given in the section "Bulk Density and Closure of Fabrics by Swelling," were made as described below.

Fabric No. 123 (Table II) can be taken as an example. Its bulk density of 0.79 (Table IV) represents the weight of cotton in 1 cc. of the fabric. This fabric, as well as others under consideration, was assumed to have 7% regain and is called "airdry." As explained earlier, the swelling corresponding with a given regain is considered equal to the regain and directly additive to the volume of cotton that corresponds with its density in water. Cotton at this density, 1.61, and specific volume, 0.621, is called "dry" for the present purpose.

If added to 1 g. of such dry cotton, 7% regain would change its weight to 1.07 g.; if additive to swelling, 7% regain would change its volume from 0.621 to 0.691. Then the density at 7% regain would be 1.07/0.691, or 1.548. Bulk

density, 0.79 (weight of air-dry cotton) divided by its density, 1.548, gives 0.51, the volume of air-dry cotton in the 1 cc. of fabric. The corresponding volume of dry cotton, upon which swelling is based, is found from the relation:

$$0.691 : 0.51 :: 0.621 : x$$

The value of "x" is 0.458, or there is 45.8% by volume of dry cotton in the fabric and, by difference, 54.2% of air space.

This cotton would therefore, have to swell by 54.2/45.8, or 118%, to just fill the fabric if the latter retained its original dimensions upon swelling. Yarn ravelled from this fabric in the grey was found to swell by 72.9% (Table II); and if fully swollen in the piece it would have filled 79.2% of the fabric volume (45.8 plus 72.9% of 45.8). Since the cloth actually swelled 48.6% (Table II), as calculated from the regain intercept, it was 68.1% filled (calculated as above) if there were no change of dimensions.

Inferences from such values as just discussed have already been presented.

SUMMARY

Swelling of cotton can contribute to the closing of swelling-type, water-resistant fabrics to help resist the passage of water, but only a few of the most tightly constructed experimental fabrics can be considered actually to have been closed by swelling. More effective fabrics can undoubtedly be produced. Reasons why it is difficult to take advantage of swelling in oxford fabrics have been brought out by means of airflow, orifice, centrifuge, and hydrostatic tests, in the absence of methods for the direct measurement of the contribution of swelling to water resistance.

There has been throughout the work a notable decrease in water resistance due to finishing, caused partly by increase in openness of texture. This opening of experimental fabrics was found not to be due to possible effects of tension and stretching during finishing; but mainly to loss of non-cellulosic constituents in scouring, which leaves more space to be filled by swelling. To add to the difficulty of closing the fabric, there is a progressive loss of swelling capacity during finishing. This was clearly shown by large increases in orifice test seepages through samples of yarn taken from fabrics at the principal steps in finishing. There is a pronounced loss even after scouring, and further losses from dyeing and water repellency teatment.

Especially notable are great differences between the swelling capacities of different cottons as estimated by the centrifuge. A mature cotton appeared to swell by 52.2% in water at room temperature and a highly immature cotton by 72.9%. These amounts decreased during finishing to about 36% and 41%, respectively. Hence, the apparent advantage of immature cotton was reduced to 5% in terms of swelling, and this would probably be offset by the loss of at least 4 to 5% more noncellulosic constituents from the immature than from the mature cotton. Hence, immature cottons are not especially suitable for swelling-type fabrics that have to be finished. There was evidence (Parts II and III) that cottons of about average maturity (76 to 81% on the U.S.D.A. scale) may be preferable to either highly mature or highly immature cottons for such goods.

Hydrostatic tests have indicated that firmly held air in a partially swollen fabric may contribute to water resistance in a way apparently not recognized heretofore, and not due merely to the usual water repellency. This effect might be mistaken for that of swelling, and may quite possibly add to the water resistance of a fabric in service in the rain, especially if previously exposed to very humid conditions.

Table I. *Orifice seepages of water and nonswelling liquids*

Yarn description (filling)	Seepage in 10 minutes		
	Water	Dioxane	Methyl amyl ketone
	ml	*ml*	*ml*
Grey	11	65	..
Scoured	15	72	..
Dyed	22	66	..
Finished	29	74	..
Grey	9.5	41	66
Scoured	11	47	71
Dyed	13	49	72
Finished	15	47	71

Table II. *Water retention and swelling at different stages in finishing (Centrifuge method)*

		Retention (intercept)								Swelling [2]			
						Yarns from fabric [1]							
Cotton	Maturity	Raw stock	Grey yarn (30/2)	Fabric number	Picks per inch	Grey	Scoured	Dyed	Finished	Grey	Scoured	Dyed	Finished
	%	%	%			%	%	%	%	%	%	%	%
RAW STOCK AND YARN:													
Deltapine	85	34.2	33.4	114	56	31.9	30.1	25.4	22.6	...	...	...	...
				118	72	32.9	29.2	24.6	22.2	...	...	...	...
				Average		32.4	29.7	25.0	22.4	52.2	47.8	40.3	36.1
"Sike"	30	48.5	45.9	119	56	45.4	39.8	30.6	25.8	...	...	...	...
				123	72	45.2	38.7	30.8	25.3	...	...	...	...
				Average		45.3	39.3	30.7	25.6	72.9	63.3	49.4	41.2
FABRICS:													
Deltapine	85	...	...	114	56	27.2	26.3	22.2	19.5	43.8	42.4	35.7	31.4
				118	72	22.6	21.9	19.9	18.1	36.4	35.3	32.0	29.1
"Sike"	30	...	...	119	56	36.0	35.4	28.9	23.6	58.0	56.9	46.5	38.0
				123	72	30.2	29.6	26.2	21.6	48.6	47.7	42.2	34.8

[1] Yarn data under this heading were obtained on yarns ravelled from fabrics at different steps in finishing.

[2] Values for swelling were obtained by dividing values of the intercepts (on the retention, or regain, axis) by 0.621 (see Special Methods).

Table III. *Effects of methods of preswelling on leakage through water-repellent Fabrics*

Fabric number	Expt. No.	Treatment	Moisture regain [1]	Hydrostatic head	Leakage (Suter, 86 cm head) [2] Original	After 3 min. boil
			%	cm	ml/10 min	ml/10 min
117F (128 x 66)	1	Control	5.8	73	17	292
	2	22 hr. in water vapor	14.8	87	0.4	163
	3	24 hr. (80° F.), 100-cm head	46.1 [3]	..	115	240
	4	1 hr. (80° F.), 100-cm head	19.3 [3]	..	1.0	452
	5	10 min. boil, 50-min soak (80° F.)	51.1 [3]	..	345	296
	6	1 hr. boil, 50-min soak (80° F.)	51.1 [3]	..	401	344
131F (128 x 64)	7	Control	5.5	69	63	681
	8	22 hr. in water vapor	15.2	79	13	625
	9	24 hr. (80° F.), 100-cm. head	32.8 [3]	..	480	...
	10	10 min. boil, 24-hr. soak (80° F.)	37.5 [3]	..	425	...

[1] Based on dry weight of cotton.

[2] Note that leakages were observed for 10 minutes rather than 5 minutes in other tables.

[3] Determined after light blotting of samples.

Table IV. *Relation of closing by swelling to bulk density*

Fabric number	Maturity of cotton	Construction Warp	Construction Filling	Bulk density	Hydrostatic leakage, prewet samples, 86-cm. head	Bundesmann penetration, prewet samples	Rain test 8-ft. head, sample 6 in. from nozzle
	%	*ends*	*picks*		*ml/5 min*	*ml/20 min*	*gm./20 min*
A. GREY:							
101	74	122	54	0.69	382	12	Over 10
102	74	122	60	.73	67	0.1	1.68
103	74	122	68	.81	1.7	.0	.48
104	74	122	69	.80	.1	.0	.44
105	74	122	71	.83	.0	.0	.44
107	58	124	68	.81	.1	.0	.54
111	85	126	68	.80	7.9	.0	.52
117	85	124	68	.74	74	.0	.93
118	85	124	72	.80	20	.0	.62
122	30	124	68	.73	1.0	.0	.45
123	30	125	73	.79	.1	.0	.32
131	84	124	64	.71	195	.3	...
133	56	124	65	.71	39	.0	...
B. FINISHED:							
101	74	124	53	.72	1900	14	3.66
102	74	124	60	.78	476	0.1	.58
103	74	122	69	.84	27	.0	.36
104	74	122	70	.84	18	.0	.42
105	74	122	71	.87	9.2	.0	.35
107	58	130	66	.82	339	.0	.98
111	85	130	67	.85	122	.0	.47
117	85	128	66	.80	264	.0	.53
118	85	130	70	.83	126	.0	.45
122	30	130	65	.80	509	.6	.57
123	30	130	71	.83	176	.1	.44
131	84	128	64	.79	399	2.7	...
133	56	129	63	.81	259	.8	...

Table V. *Compression of yarn in fabrics shown by the Orifice test*

Fabric number and kind of cotton	Picks per inch (grey)	Maturity of cotton	Seepages in orifice test Grey	Seepages in orifice test Finished
		%	*ml/10 min*	*ml/10 min*
114 Deltapine	56	85	10.21	26.01
115 Deltapine	60	85	12.08	30.09
116 Deltapine	64	85	13.14	28.57
117 Deltapine	68	85	11.58	37.55
118 Deltapine	72	85	13.56	37.04
119 "Sike"	56	30	.53	7.61
120 "Sike"	60	30	.45	7.10
121 "Sike"	64	30	.49	8.53
122 "Sike"	68	30	.55	9.78
123 "Sike"	73	30	.77	11.37

LITERATURE CITED

1. Anonymous, *Am. Dyestuff Reptr. 33,* 552 (1944).
2. Anonymous, *J. Textile Inst. 38,* S1-S14 (1947); 46, S51-S56 (1955).
3. Anonymous, *Textile Recorder 65* (770), 48 (1947).
4. American Association of Textile Chemists and Colorists, "Technical Manual and Year Book," Vol. 34, 142-152 (1958).
5. American Society for Testing Materials, "A.S.T.M Standards on Textile Materials," Philadelphia, 1958.
6. Ashpole, D. K., Proc. Roy. Soc. London A212, 112-122 (1952).
7. Baringer, K. L. Schuyten, H. A., and Goldthwait, C. F., *Textile Industries 118* (7), 102-105 (1954).
8. Baxter, S., and Cassie, A. B. D., *J. Textile Inst 36* T67-T90 (1945).
9. Brown, J. J., and Rusca, R. A., *Textile Research Journal 25,* 472-476 (1955).
10. Dorkin, C. M., and Chamberlain, N. H., *J. Textile Inst. 47,* T371-T384 (1956).
11. Goldthwait, C. F., *Am. Dyestuff Reptr. 27,* P70-P76 (1938).
12. Goldthwait, C. F., U. S. Patent 2,352,707 (July 4, 1944).
13. Goldthwait, C. F., Murphy, A. L., Lohmann, I. W., and Smith, H. O., *Textile Research Journal 22,* 540-548 (1952).
14. Goldthwait, C. F., and Smith, H. O., *Textile World 95* (7), 105, 107, 196, 198 (1945).
15. Goldthwait, C. F., Smith, H. O., and Barnett, M. P., *Textile World 97* (7), 105-108, 201-202, 204, 206 (1947).
16. Harris Research Laboratory, Washington, D. C., "Quartermaster Research on Water Resistant Textiles," U. S. Quartermaster Corps, Research and Development Branch, Military Planning Division, Textile Ser. Rept. 37, 186 pp. (1951).
17. Hermans, P. H., "Contribution to the Physics of Cellulose Fibers," p. 82, Elsevier, Amsterdam, 1946.
18. Kennedy, S. J., *Textile Research Journal 24,* 572-577 (1954).
19. Lord, J., *J. Textile Inst. 47,* P41-P61 (1956).
20. McCall, E. R., and Jurgens, J. F., *Textile Research Journal 21,* 19-21 (1951).
21. Mayer, M., Jr., Kyame, G. J., and Brown, J. J., *Textile World 102* (7), 114-115, 210 (1952).
22. Minor, F. W., Sookne, A. M., Simpson, J. E., and Harris, M., *Textile Research Journal 16,* 539-544 (1946).
23. Moore, A. T., Scott, L. W., deGruy, I. V., and Rollins, M. L., *Textile Research Journal 20,* 620-630 (1950).
24. O'Brien, W. E., and Weiner, L. I., *Textile Research Journal 24,* 241-250 (1954).
25. Peirce, F. T., *Textile Research Journal 17,* 123-157 (1947).
26. Peirce, F. T., British Cotton Industry Research Association, Gardiner, W. C., and F. Reddaway and Co., Ltd., British Patent 549,974 (December 16, 1942).
27. Peirce, F. T., and Gardiner, W. C., (to British Cotton Industry Research Association and F. Reddaway and Co., Ltd.), U. S. Patent 2,350,-696 (June 6, 1944).
28. Pfeiffenberger, G. W., *Textile Research Journal 16,* 338-343 (1946).
29. Pickard, R. H., *J. Textile Inst. 34,* P95-P102 (1943).
30. Preston, J. M., and Nimkar, M. V., *Textile Research Journal 23,* 64-65 (1953).
31. Reid, J. D., and Goldthwait, C. F., U. S. Dept. Agr. Yearbook of *Agr.*, 1950/1951, 411-418,
32. Segall, G. H., *Textile Research Journal 22,* 736-741 (1952).
33. Simpson, J. E., *Am. Dyestuff Reptr. 35,* 243-252, 272, 288-290 (1946).
34. Smith, H. O. (speaker), and Southeastern Sect. AATCC Committee, *Am. Dyestuff Reptr. 39,* P74-P77, P90 (1950).
35. Smith, H. O., Murphy, A. L., and Goldthwait, C. F., *Textile Research Journal 18,* 124-129 (1948).
36. Welo, L. A. Ziifle, H. M., and Loeb, L., *Textile Research Journal 22,* 254-261 (1952).
37. Welo, L. A., Ziifle, H. M., and McDonald, A. W., *Textile Research Journal 22,* 261-273 (1952).